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Determination of Acoustic Effects on Marine Mammals and Sea Turtles for the Gulf of Alaska Training Activities Supplemental Environmental Impact Statement/Overseas Environmental Impact Statement

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PREFACE

This report was prepared under Funding Document N0007012WR4C709,"Marine Species Study," program manager Peter H. Hulton (Code 709). The sponsoring activities are U.S. Fleet Forces Command (USFF), Naval Sea Systems Command, and Naval Air Systems Command.

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14. ABSTRACT. The United States Navy is required to assess potential effects of Navy-generated anthropogenic sound in the water in order to comply with federal environmental laws and regulations, including the National Environmental Policy Act, Executive Order 12114, the Marine Mammal Protection Act, and the Endangered Species Act. The acoustic effects assessment for Phase II of the Tactical Training Theater Assessment and Planning Program uses quantitative analysis methodology to estimate acoustic exposures on designated marine fauna, which include marine mammals and sea turtles. This report describes the process used to determine the number of modeled acoustic exposures for marine mammals and sea turtles as a result of the Navy's training and testing in the Gulf of Alaska Training and Testing Study area.

15. SUBJECT TERMS
Acoustic Footprints, Acoustic Modeling, Environmental Impact Statement, Marine Mammals, Navy Acoustic Effects Model, Overseas Environmental Impact Statement, Permanent Threshold Shift, Tactical Training Theater Assessment and Planning Program, Temporary Threshold Shift

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EXECUTIVE SUMMARY

Since 1997, the U.S. Navy has modeled the potential acoustic effects on marine mammals and sea turtles from specific Navy training and test activities. Various models used "area density" approaches in which acoustic footprints were computed and then multiplied by animal densities to calculate effects. As a result of a review conducted by the Center for Independent Experts, as required by the National Marine Fisheries Service, the Navy refined its process. The new model—The Navy Acoustic Effects Model (NAEMO)—is the standard model now used by the Navy to estimate the potential acoustic effects of proposed Navy training and testing activities on marine mammals and sea turtles. Therefore, it is an integral component to the Navy's ongoing commitment to environmental stewardship and operational sustainment. This report describes the process used to implement NAEMO for activities occurring in the Gulf of Alaska (GOA) Training Study Area/Temporary Maritime Activities Area (TMAA).

NAEMO is comprised of seven modules: Scenario Builder, Environment Builder, Acoustic Builder, Marine Species Distribution Builder, Scenario Simulator, Post Processor, and Report Generator. Scenario Builder is a graphical user interface (GUI)-based tool that defines where an activity would occur, the duration of the activity, a description of the activity, and what platforms would be participating. Once a platform is identified, all the sound sources typically associated with that platform are displayed, thus providing standardization and repeatability when different analysts are entering data. Individual sources can be turned on or off according to the requirements of the scenario. Platforms are either stationary or can be moved through the action area in either a defined track or random straight-line movement.

Environment Builder is a GUI that extracts all of the oceanographic and environmental data required for a scenario simulation. When an area is selected, information on bathymetry, sound speed profiles, wind speeds, and bottom properties are extracted from an array of points across the region, using Oceanographic and Atmospheric Master Library (OAML) databases. Seasonal averages are created for the sound speed profiles and wind speeds from historical average values.

Acoustic Builder is a GUI that generates acoustic propagation data. It reads the Scenario Builder file, allows the user to define analysis points for propagation software, and creates the propagation model inputs. Depending on the source characteristics, the propagation models utilized are Comprehensive Acoustic Simulation System/Gaussian Ray Bundle (CASS/GRAB), Range-Dependent Acoustic Model (RAM), or Reflection and Refraction in Multilayered Ocean/Ocean Bottoms with Shear Wave Effects (REFMS).

Marine Species Distribution Builder is a module that allows the user to distribute marine species within the modeling environment in accordance with the bathymetry and relevant descriptive data. Marine species density data, which include seasonal information when available, are obtained from the Navy Marine Species Density Database (NMSDD); the sizes of cells and density of marine species within each cell vary by species and location.

Scenario Simulator executes the simulation and records the sound received by each marine mammal and sea turtle in the area for every time step that sound is emitted; it incorporates the scenario definition, sound propagation data, and marine species distribution data, ultimately providing raw data output for each simulation. Most scenarios are run in small, 4- to 12-hour segments based on representative training and testing activities. Some scenarios are evaluated by platform and single locations, while others are evaluated in multiple locations within a single range complex or testing range. Within each scenario, multiple ship track iterations are run to provide a statistical set of raw data results.

Post Processor provides the computation of estimated effects that exceed defined threshold criteria from each of the raw data files produced by Scenario Simulator. It also affords the option to review the output data through a series of tables and graphs.

Report Generator enables the user to assemble a series of simulation results created by multiple post-processing runs and produce a combined result. Multipliers can be applied to each scenario to compute the effects of conducting them multiple times. Results can also be exported via Microsoft Excel files for further analysis and reporting.

Modeled effects from NAEMO are used to support analyses in the GOA Training Activities Supplemental Environmental Impact Statement/Overseas Environmental Impact Statement, mitigation strategies, and documentation associated with Endangered Species Act Biological Evaluations and Marine Mammal Protection Act permit applications.

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LIST OF ABBREVIATIONS AND ACRONYMS

2-D	Two-dimensional
3-D	Three-dimensional
ADC	Countermaesure
ASCII	American Standard Code for Information Interchange
ASW	Antisubmarine Warfare
BRF	Behavioral risk function
CASS	Comprehensive Acoustic System Simulation
CSGEX	Carrier Strike Group Exercise
CV	Coefficient of variation
CVN	Aircraft Carrier, Nuclear Propulsion
DDG	Guided Missile Destroyer
DICASS	Directional Command Active Sonobuoy System
EIS	Environmental Impact Statement
f	Frequency of interest
GI	Gastrointestinal
GOA	Gulf of Alaska
GRAB	Gaussian Ray Bundle
GUI	Graphical user interface
HARM	High-speed Anti-radiation missile
HF	High frequency
IMS	Imaging Sonar
LF	Low frequency
M	Modem
MF	Mid-frequency
NAEMO	Navy Acoustic Effects Model
NIXIE	Electronic Device for Displaying Numerals or other Information using Glow Discharge
NMFS	National Marine Fisheries Service
NMSDD	Navy Marine Species Density Database
NODES	Navy Operating Area Density Estimates
NUWC	Naval Undersea Warfare Center
OAML	Oceanographic and Atmospheric Master Library
OEIS	Overseas environmental impact statement
OPAREA	Operational Area
P	Pingers
PTS	Permanent threshold shift
R	Releases
RAM	Range-Dependent Acoustic Model
RDX	Research Department Explosive (cyclotrimethylenetrinitramine)
REFMS	Reflection and Refraction in Multilayered Ocean/Ocean Bottoms with Shear Wave Effects
RES	Relative Environmental Suitability
RMS	Root-Mean-Square
SD	Surface Duct
SEL	Sound exposure level
SMRUL	Sea Mammal Research Unit Ltd

LIST OF ABBREVIATIONS AND ACRONYMS (cont'd)

SPL	Sound pressure level
SSS	Side-Screen-Sonar
TMAA	Temporary Maritime Activities Area
TNT	Trinitrotoluene
TORP	Torpedo
TTS	Temporary threshold shift
USFF	U.S. Fleet Forces Command
VD	Variable Depression
VHF	Very high frequency

DETERMINATION OF ACOUSTIC EFFECTS ON MARINE MAMMALS AND SEA TURTLES FOR THE GULF OF ALASKA TRAINING ENVIRONMENTAL IMPACT STATEMENT/OVERSEAS ENVIRONMENTAL IMPACT STATEMENT

1. INTRODUCTION

The U.S. Navy is required to assess potential effects of Navy-generated anthropogenic sound in the water on marine species in order to comply with a suite of federal environmental laws and regulations, including the National Environmental Policy Act, Executive Order 12114, the Marine Mammal Protection Act, and the Endangered Species Act. The acoustic effects analysis for Phase II of the Navy's comprehensive at-sea planning program* uses, when supported by data, quantitative methodology to estimate acoustic effects on marine species.

Since 1997, the Navy has invested considerable effort and resources in the modeling and analysis of the estimated acoustic effects of underwater sound sources on marine mammals and sea turtles. A National Marine Fisheries Service (NMFS)-required Center for Independent Experts review of the various approaches to Navy acoustic effects analyses led to refinement of the methodology, which has culminated in the development of a standard Navy model for acoustic effects, the Navy Acoustics Effects Model (NAEMO). NAEMO is used to support the evaluation of the potential effects of proposed Navy actions on marine mammals and sea turtles for Phase II acoustic effects analyses. The model utilizes standardized input parameters such as operational environments, marine species density, and active acoustic source parameters, all of which are addressed in detail in later sections.

This report describes the process used to model estimated effects on marine mammals and sea turtles as a result of the Navy's training in the Gulf of Alaska (GOA) Temporary Maritime Activities Area (TMAA). Modeled activities include the use of active sonar and explosive events occurring during a major training exercise (i.e., Northern Edge) within the GOA TMAA.

Exercise activities will occur within the TMAA and a single warning area in the eastern North Pacific Ocean region within the GOA (figure 1).

* Phase II meets the Navy's requirement to develop a programmatic approach to environmental compliance for range complexes and testing ranges. GOA is part of the second phase of this planning program, updating prior analysis with a new standard model used to estimate the potential acoustic effects of proposed Navy activities on marine mammals within GOA. (There was no sea turtle density available for GOA so these species were not modeled).

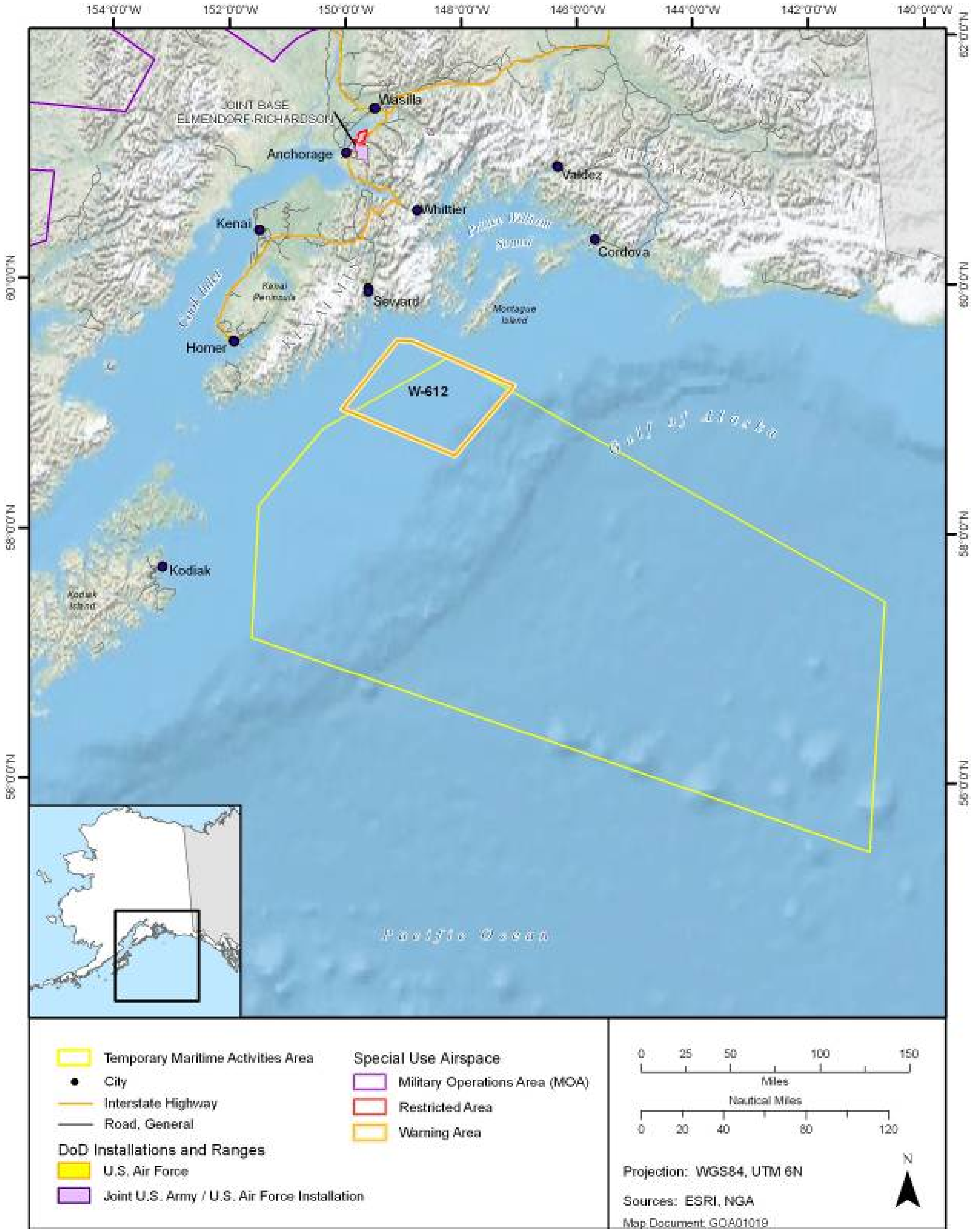

Figure 1. Gulf of Alaska Temporary Maritime Activities Area

1.1 MODELING AND SIMULATION

The terms modeling and simulation are used throughout this report. Modeling refers to a conceptualized view of reality along with the underlying assumptions and constraints. Simulation is the execution of a model over time. These definitions suggest that modeling resides on the abstract level and simulation resides on the implementation level.

NAEMO software provides acoustic modeling parameters for the purpose of estimating effects on marine mammals and sea turtles. The simulation aspect is the execution of the model to generate results, in this case, effect estimates, based on different sets of inputs.

1.2 COMPARISON WITH PHASE I

Phase I of the Navy's at-sea environmental planning and permitting effort addressed Fleet training activities. Different modeling processes were used to estimate the effects of sound on marine species incidental to military readiness activities. Phase II analysis of the GOA TMAA evaluates the same geographic area and training activities (with additional analysis of several new sources) using the same standard acoustic model used in all other Phase II environmental documents. Using methodologies standardized for Phase II eliminates the varying modeling processes previously used between study areas and provides consistency of acoustic modeling output.

The first step in the Phase I modeling process involved propagation modeling. For sonars, the Comprehensive Acoustic System Simulation (CASS)/Gaussian Ray Bundle (GRAB) model was used. Explosive sources were analyzed using both Reflection and Refraction in Multilayered Ocean/Ocean Bottoms with Shear Wave Effects (REFMS) or a modified version of CASS/GRAB. Phase II modeling retains some of the Phase I features, such as use of the same propagation model (i.e., CASS/GRAB), for developing tonal source footprints. Phase II uses REFMS exclusiveley for explosive propagation.

For Phase I, footprints were created for each active source used in an activity, and the movements of the source were modeled over the operating area. Only one source type was modeled at a time. Unlike Phase I, NAEMO has the capability to simultaneously run multiple sources during a scenario, affording a more realistic depiction of the potential effects of an activity. For example, transmissions emitted by a surface combatant with its hull-mounted sonar, a helicopter with its dipping sonar, a torpedo's homing sonar, and the countermeasures discharged by the targeted submarine can be modeled simultaneously.

Although the acoustic propagation was modeled in three dimensions during Phase I analyses, in some cases, the three-dimensional (3-D) footprint was collapsed into a two-dimensional (2-D) acoustic footprint by utilizing the maximum received level, irrespective of the depth, at each range step. In other areas, a volumetric, 3-D footprint was developed to allow for variations in animal depth. For Phase II analyses, the 3-D acoustic propagation field was maintained throughout the analysis process.

Phase I distributed marine species uniformly in the respective density cells over the area being modeled. The animals were distributed in two dimensions, except in locations where data for species-specific dive profiles were available. In those areas, the animals were distributed in 3-D. In the 2-D distribution, all animals within the range of the maximum energy field would be affected, while in the volumetric approach, effects depended on where the animals were in the water column in relation to the propagation pattern. In Phase II, data on species-specific habitat preference, podding behavior, and dive profiles were taken into account and used to distribute individual animals in the model. An animat, is a generic term that denotes an artificial or virtual animal used during modeling (Wilson, 1990), serves as a dosimeter, recording the energy received from all active sources during a scenario, resulting in the cumulative effects of all sources being accounted for when the impacts are analyzed.

Another difference between Phase I and Phase II modeling involves the environmental data used during propagation modeling. Phase II incorporates bathymetry into the propagation modeling process for non-impulsive sources and non-explosive impulsive (i.e., airgun) sources; Phase I used flat-bottomed bathymetry. Flat-bottom bathymetry will continue to be used in Phase II for all impulsive sources, as it was in Phase I. Futhermore, Phase II uses range-dependent sound speeds, wind speed, and bottom properties.

1.3 MODELING SOFTWARE OVERVIEW

The NAEMO software suite consists of seven modules, as depicted in figure 2. All software modules are accessed via a graphical user interface (GUI). The following sections identify the data inputs, implementation, and outputs from each of these modules. Data are processed through each of these modules as depicted in figure 3.

1.4 STANDARDIZATION AND REPEATABILITY

Standardization and repeatability are reflected in the implementation process and in the NAEMO Modeling Business Rules. Standardized datasets are used by all analysts to develop scenarios. Modeled scenarios and associated setup files are archived to ensure repeatability.

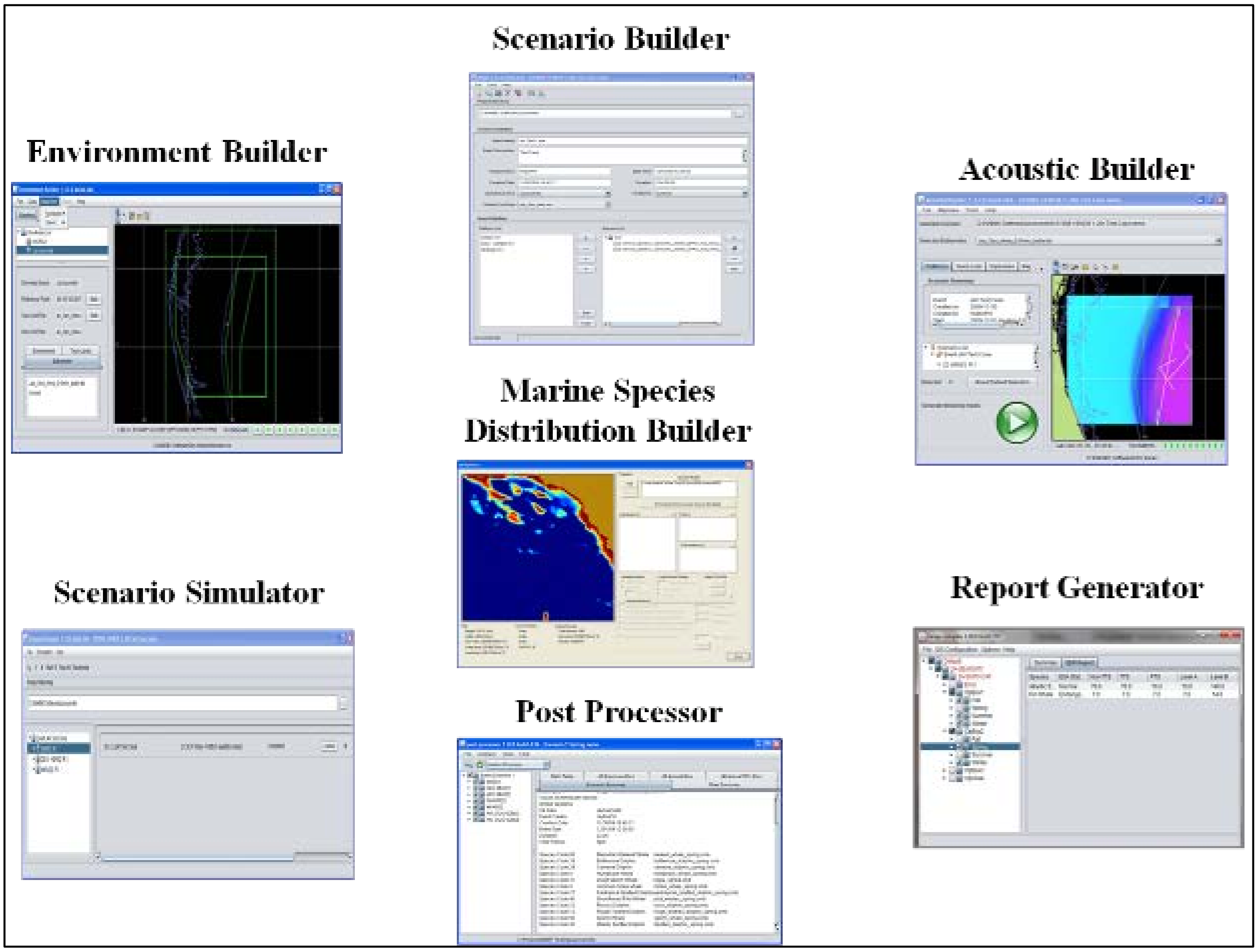

Figure 2. Navy Acoustic Effects Model Software Modules

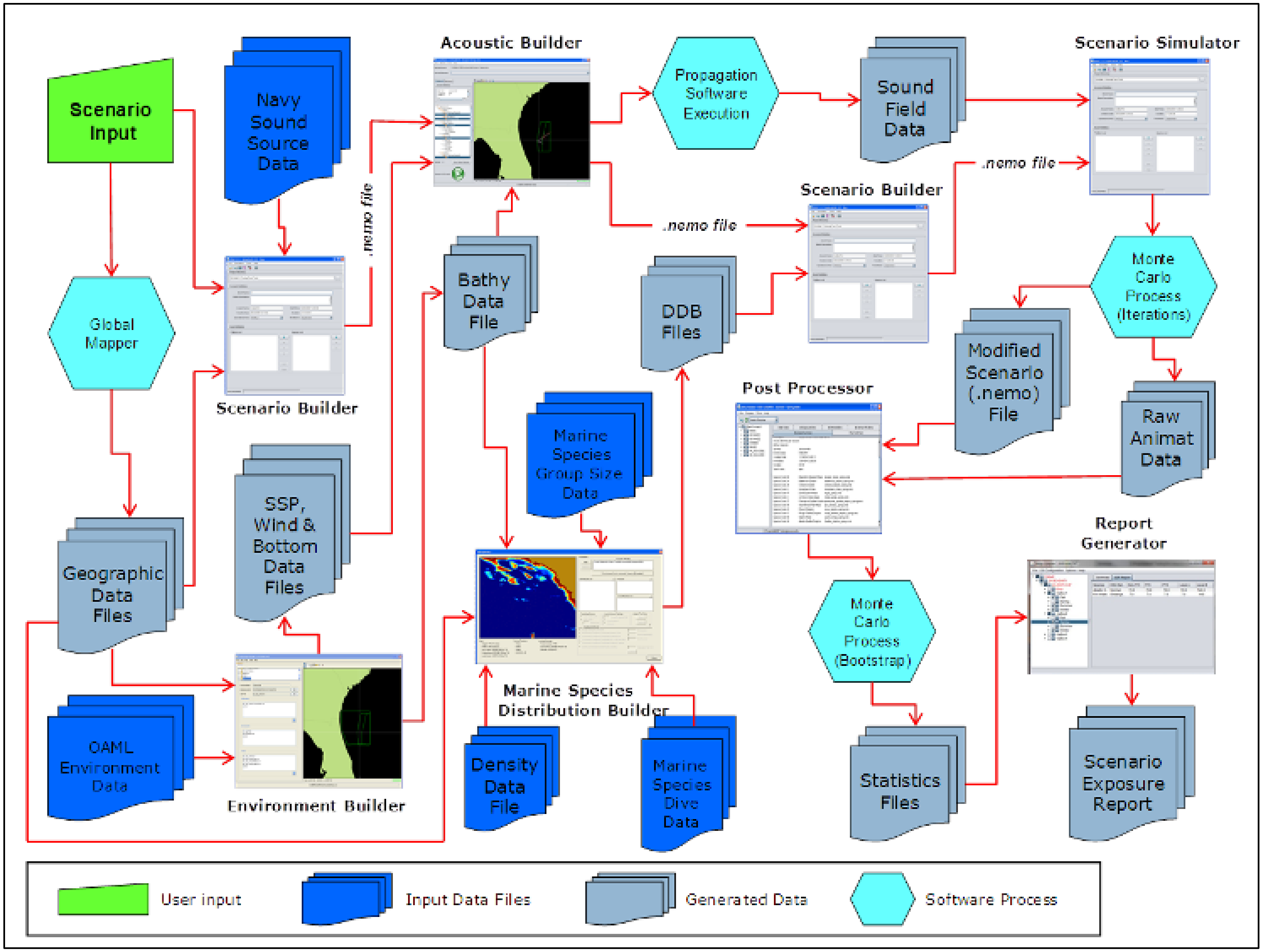

Figure 3. Navy Acoustic Effects Model Data Flow Path

2. SCENARIO DEVELOPMENT

This section describes the scenario development process for training activities. Additionally, brief descriptions of the scenarios are provided. All of the training activities are described in appendix A of the GOA Supplemental Environmental Impact Statement/Overseas Environmental Impact Statement (EIS/OEIS). For each activity, the locations and number of events anticipated per year are provided in chapter 2, Description of Proposed Action and Alternatives, of the GOA Supplemental EIS/OEIS.

2.1 PURPOSE

The scenario working group was comprised of subject matter experts from the Commander Pacific Fleet staff. Scenarios were modeled during the summer, in the locations within the GOA TMAA where training has historically occurred or are predicted to occur. The actual locations of training activities throughout the study area may vary based on emergent need.

An additional goal was to standardize the scenarios throughout all Navy Study Areas so that an activity occurring in the Atlantic Ocean is modeled consistently with the same activity occurring in the Pacific Ocean including the Gulf of Alaska. Where possible, the modeling scenarios are consistent in duration, number and types of sensors employed, and number of platforms. Only the geographic location of the activity may vary. Specific exercise details occasionally change to meet current operational needs, but these minor adjustments to the intensity and type of the activity would be similar to the modeled event.

2.2 LEVELS OF ACTIVITY

The total numbers of events were determined for the main GOA major exercise, Carrier Strike Group Exercise (CSGEX). For all activities, the number of events is provided in chapter 2, Description of Proposed Action and Alternatives, of the GOA Supplemental EIS/OEIS. The training scenarios were developed separately by representatives from each scenario working group to utilize subject matter expertise within each group. The number of scenarios modeled accounts for typical variability in training requirements by modeling the number of scenarios that could occur during a typical year of high exercise activity. This is necessary to ensure that the Navy does not exceed the Use authorizations in any given year.

2.2.1 CSGEX Major Exercise

A CSGEX involves numerous participants, lasts multiple days, and is conducted over a large area. The number of major training exercises in the TMAA was primarily based on the Fleet Readiness Training Plan and the mission certification requirements of the individual warfare communities.

2.3 SCENARIO DESCRIPTIONS

All modeling scenarios for training activities are notional because predicting, with precision, the composition or exact location of events that will occur in the 2016-to-2021 timeframe is not possible. Each exercise may also be conducted differently because of varying environmental conditions in the exercise area that affect the selection of tactics and procedures used to effectively complete a training activity on a given day. The major factors that can impact the composition of training activities are described in more detail in the following sections.

2.3.1 Platforms and Sources

The number and types of platforms that participate in a given type of activity can vary due to numerous factors, including deployment schedules, number of ships assigned to a strike group, and planned or unplanned maintenance of ships and systems. For example, if three to five surface ships normally participate in a given antisubmarine warfare exercise, the representative modeling scenario for this event would consist of four surface ships. The composition of this exercise represents the average number of antisubmarine warfare-equipped ships and types of sonar that would be used during a typical antisubmarine warfare exercise.

2.3.2 Source Usage

Prior to Phase II, many modeled events varied considerably between Study Areas. Differences could include the duration of the event, number of platforms participating in the event, numbers and types of sensors deployed, and sonar modes utilized. For Phase II, similar activities occurring in multiple locations, either within the same Study Area or across Study Areas, were defined with the same scenario description to ensure consistency.

2.3.3 Locations

Modeling locations were developed based on historical data and anticipated future needs within the GOA TMAA.

2.3.4 Modeling Area Size

Modeling boxes were developed to represent the area that an activity is likely to utilize. Longer and more complex scenarios, such as a CSGEX, generally use a larger area, while shorter duration events, such as unit-level training activities, utilize a much smaller modeling area. Typical modeling box sizes are provided in table 1. Multiple modeling areas were used for each activity to ensure that a broad area analysis was conducted to account for all areas in which an activity could occur. The number of modeling boxes distributed within a particular location was based on the overall size of the location, size of the modeling box, and bathymetric and sound speed variability within the location. Modeling boxes were evenly distributed across each modeling location.

Table 1. Example Modeling Box Areas and Typical Scenarios

Area (nm^2)	Typical Scenarios
50	Bombing Exercise, Gunnery Exercise
3600	Major Training Exercise
3600	Multistatic Active Coherent Sonobuoy Tracking Exercise

3. MODELED TRAINING AREAS

The TMAA is a temporary area established in conjunction with the Federal Aviation Administration for up to 21 days per Northern Edge exercise. The TMAA is a surface, undersea space, and airspace maneuver area within the GOA for ships, submarines, and aircraft to conduct required training activities. As depicted in figure 4, the TMAA is a polygon roughly resembling a rectangle oriented from Northwest to Southeast, approximately 300 nm in length by 150 nm in width, located South of Prince William Sound and East of Kodiak Island. With the exception of Cape Cleare on Montague Island, located approximately 12 nm from the Northern point of the TMAA, the nearest shoreline (Kenai Peninsula) is located approximately 24 nm North of the TMAA's Northern boundary. The approximate middle of the TMAA is located 140 nm offshore.

Modeling areas were selected to depict the representative areas in the GOA TMAA within which an activity is expected to occur. Figure 4 provides an overview of the GOA TMAA offshore modeling areas.

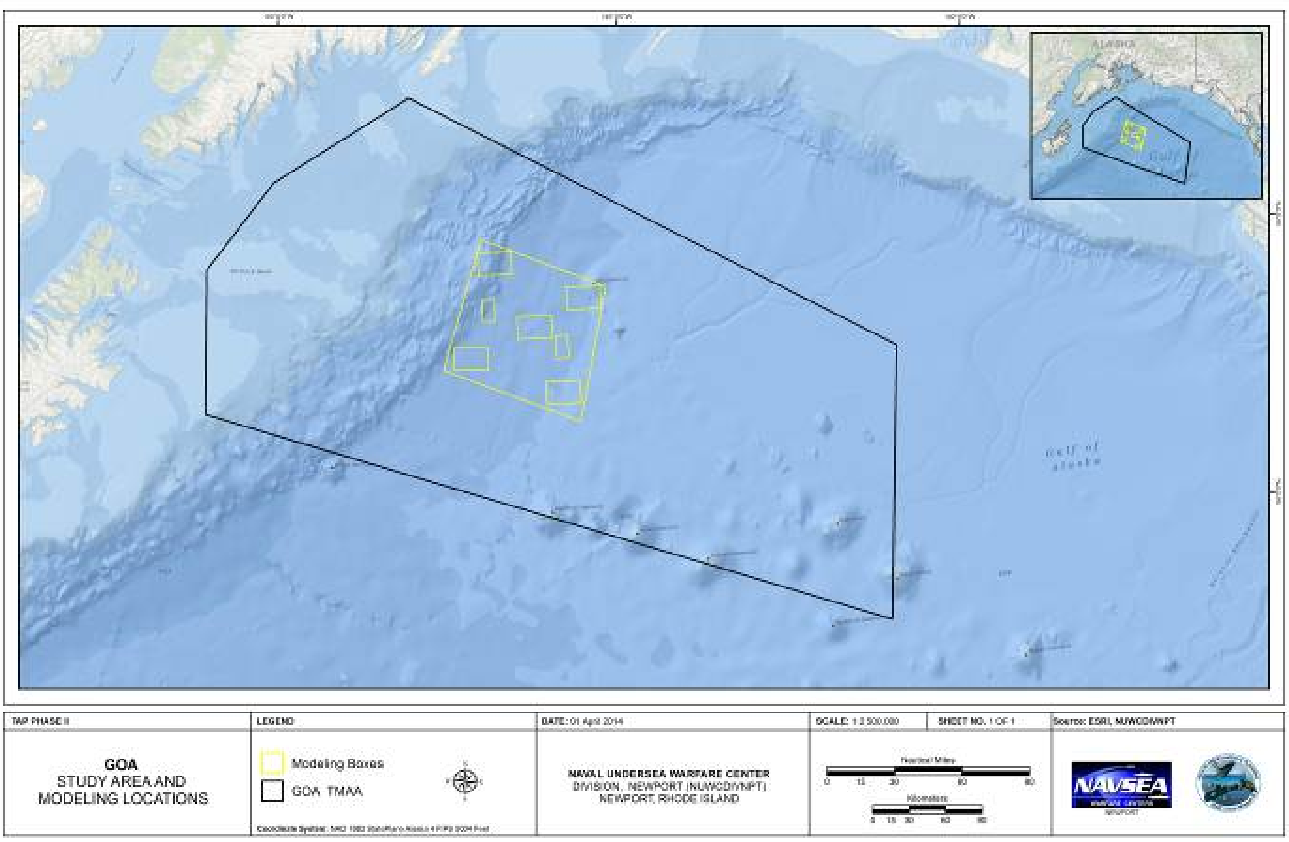

Figure 4. Offshore Track Boundaries and Modeling Areas

4. SOUND SOURCES

All Fleet and Systems Commands participants were polled for an inventory of systems involved with current Navy activities, along with systems that were anticipated to be used over the life of the Phase II documents. The results of these efforts culminated in the Navy Sound Source Data file.

4.1 TERMINOLOGY

Acoustic sources were divided into two categories, impulsive and non-impulsive. Impulsive sounds feature a very rapid increase to high pressures, followed by a rapid return to static pressure. Impulsive sounds are often produced by processes involving a rapid release of energy or mechanical impacts (Hamernik and Hsueh, 1991). Explosions, airgun impulses, and impact pile driving are examples of impulsive sound sources. Non-impulsive sounds lack the rapid rise time and can have durations longer than those of impulsive sounds. Sonar pings and underwater transponders are examples of non-impulsive sound sources. The terms “impulsive” and “non-impulsive” were selected for use because they were deemed more technically accurate and less confusing than the terms “explosive” and “acoustic” used in previous documentation. The term “explosive” does not accommodate sources such as airguns, and “acoustic” is a generic, all-encompassing term that does not exclusively refer to all non-impulsive events.

In addition to impulsive and non-impulsive, sources can be categorized as either broadband (producing sound over a wide frequency band) or narrowband (where the energy is within a single one-third octave band). Typically, broadband is equated with impulsive sources, and narrowband with non-impulsive sources, although non-impulsive broadband sources, such as acoustic communications equipment and certain countermeasures, were also modeled. In general, most of the acoustic energy resulted from narrowband sources, such as sonars, or broadband sources, such as underwater explosions. All non-impulsive sources were modeled using the geometric mean frequency. All impulsive sources were modeled using the time series of the pressure amplitude.

The following terms are defined because they were used in the Phase II non-impulsive effects modeling and, specifically, in the determination of the received levels.

1. Source Depth—the depth of the source in meters.

2. Nominal Frequency—typically, the geometric mean of the frequency bandwidth.

3. Source Directivity—the source beam was modeled as a function of a horizontal and a vertical beam pattern.

    a. The horizontal beam pattern was defined by two parameters:
    (1) Horizontal Beamwidth—the width of the source beam in degrees measured at the 3-dB down points in the horizontal plane (assumed constant for all horizontal steer directions).
    (2) Horizontal Beam Offset—the direction in the horizontal plane that the beam was steered relative to the platform’s heading (direction of motion) (typically 0°).

b. The vertical beam pattern was defined by two parameters:
   (1) Vertical Beamwidth—the width of the source beam in degrees in the vertical plane measured at the 3-dB down points (assumed constant for all vertical steer directions).
   (2) Depth/Elevation Angle—the vertical orientation angle relative to the horizontal. This angle was measured positive down in CASS, ranging from 0 to ± 90°. It was typically zero degrees.

4. Ping Interval—the time in seconds between the start of consecutive pulses for a non-impulsive source.

5. Pulse Length—the duration of a single non-impulsive pulse, specified in seconds.

6. Signal Bandwidth—The geometric mean frequency is the square root of the product of the frequencies defining the frequency band (equation (1)):

$$f_{gm} = \left(f_{\min} \times f_{\max} \right)^{0.5}, \tag{1}$$

where, $f_{\max}$ is the upper cutoff frequency and $f_{\min}$ is the lower cutoff frequency.

7. Duty Cycle—the pulse length divided by the ping interval.

Many of these system parameters are classified and cannot be provided in an unclassified document. Each source was modeled utilizing representative system parameters based on the non-impulsive source category (described in section 4.2) within which it occurs.

4.2 SOURCE CATEGORIES

The hundreds of entries in the Navy Sound Source Data file were reduced to the active sources that were relevant to Phase II modeling, culminating in approximately 70 impulsive sources and 140 non-impulsive sources. Impulsive sources were placed into bins based on net explosive weights. Non-impulsive sources were grouped into bins that were defined in accordance with their fundamental acoustic properties such as frequency, source level, beam pattern, and duty cycle. Each bin was characterized by parameters that represented the most conservative from an acoustic propagation modeling perspective for all bin members. Specifically, bin characteristics for non-impulsive sources were selected based on (1) highest source level, (2) lowest geometric mean frequency, (3) highest duty cycle, and (4) largest horizontal and vertical beam patterns.

The use of source classification bins provides the following benefits:

- provides the ability for new sensors or munitions to be covered under existing authorizations, as long as those sources fall within the parameters of a “bin”;
- allows analysis to be conducted in a more efficient manner, without any compromise of analytical results;
- simplifies the source utilization data collection and reporting requirements anticipated under Marine Mammal Protection Act authorizations;
- ensures a conservative approach to all impacts estimates, as all sources within a given class are modeled as the loudest source (lowest frequency, highest source level, longest duty cycle, or largest net explosive weight) within that bin; and
- provides a framework to support the reallocation of source usage (hours/explosives) between different source bins, as long as the total numbers of takes remain within the overall analyzed and authorized limits. This flexibility is required to support evolving Navy training and testing requirements, which are linked to real-world events.

An unclassified version of the sources modeled within each source class category is provided in the appendix.

4.3 IMPULSIVE SOURCES

The steep pressure rise or initial rapid over and under pressure that characterize impulsive sources and their potential for structural injury are the reason they are evaluated differently than are non-impulsive ones. Impulsive sources included the following types of devices: projectiles, rockets, missiles, bombs, explosive torpedoes, and impulsive sonobuoys. Qualitative descriptions of the impulsive devices included in Phase II can be found in the GOA Supplemental EIS/OEIS. Therefore, they are not described in this report. The different types of Phase II impulsive sources were placed into the 17 categories listed in table 2.

Table 2. Impulsive Sources Modeled in the Study Area

Source Class Category*	Representative Munitions	Net Explosive Weight (pounds)
E4	Improved Extended Echo Ranging sonobuoy	> 2.5–5.0
E5	5 in. projectiles	> 5–10
E6	AGM-114 Hellfire missile	> 11–20
E7	AGM-88 High-speed Anti-Radiation missile	> 20–60
E8	AGM-65 Maverick missile	> 60–100
E9	500 lb bomb	> 100–250
E10	1,000 lb bomb, Harpoon missile, AGM-119 Penguin missile	> 250–500
E11	Classified sources	> 500–650
E12	2,000 lb bomb	> 650–1,000
* Source class refers to the net explosive weight of a munition, not to the overall weight of the munition.		

4.4 NON-IMPULSIVE SOURCES

Non-impulsive sources included the following types of devices: submarine sonars, surface ship sonars, helicopter dipping sonars, torpedo sonars, active sonobuoys, countermeasures, underwater communications, tracking pingers, unmanned underwater vehicles and their associated sonars, and other devices. Qualitative descriptions of these devices can be found in the GOA Supplemental EIS/OEIS. Therefore, they are not described in this report. Non-impulsive sources for modeled training activities in the GOA Study Area are listed in table 3.

Table 3. Non-Impulsive Sources Modeled in the Study Area

Source Class Category	Source Class	Description
Mid-Frequency (MF): Tactical and non-tactical sources that produce mid-frequency (1-to-10 kHz) signals.	MF1	Hull-mounted surface ship sonars (e.g., AN/SQS-53C and AN/SQS-61)
	MF3	Hull-mounted submarine sonars (e.g., AN/BQQ-10)
	MF4	Helicopter-deployed dipping sonars (e.g., AN/AQS-22 and AN/AQS-13)
	MF5	Active acoustic sonobuoys (e.g., DICASS)
	MF6	Active underwater sound signal devices (e.g., Mk 84)
	MF11	Hull-mounted surface ship sonars with an active duty cycle greater than 80%
High-Frequency (HF): Tactical and non-tactical sources that produce high-frequency (greater than 10 kHz but less than 200 kHz) signals.	HF1	Hull-mounted submarine sonars (e.g., AN/BQQ-10)
	HF6	Active sources (equal to 180 dB and up to 200 dB) not otherwise binned
Antisubmarine Warfare (ASW): Tactical sources such as active sonobuoys and acoustic countermeasures systems used during the conduct of ASW training and testing activities.	ASW2	MF Multistatic Active Coherent sonobuoy (e.g., AN/SSQ-125)
	ASW3	MF towed active acoustic countermeasure systems (e.g., AN/SLQ-25)
	ASW4	MF expendable active acoustic device countermeasures (e.g., Mk 3)
Torpedoes (TORP): Source classes associated with the active acoustic signals produced by torpedoes.	TORP2	Heavyweight torpedo (e.g., Mk 48).
* All decibels (dB) are referenced to 1 μPa.		

In addition to the quantitatively analyzed sources listed in table 3, additional sources were removed from quantitative analysis because they are not anticipated to result in takes of protected species. These additional sources include those of low source level, narrow beamwidth, downward-directed transmission, short pulse lengths, frequencies above known hearing ranges of marine mammals and sea turtles, or some combination of these factors. Therefore, entire source bins, or some sources from a bin, have been excluded from quantitative analysis; these bins are listed in table 4.

Table 4. Non-Impulsive Sources Utilized in the Study Area but Not Quantitatively Analyzed

Source Class Category	Source Class	Description
Fathometers HF sources used to determine water depth.	FA1-FA4	Marine mammals are expected to exhibit no more than short-term and inconsequential responses to the sonar, profiler, or pinger, given their characteristics (e.g., narrow, downward-directed beam). Such reactions are not considered to constitute "taking". Therefore, no additional quantitative modeling is required for marine species that might encounter these sound sources. Fathometers use a downward-directed, narrowly focused beam directly below the vessel (typically much less than 30 degrees), using a short pulse length (less than 10 msec). Use of fathometers is required for safe operation of Navy vessels.
Hand-Held Sonar HF sonar devices used by Navy divers for object location.	HHS1	Hand-held sonars generate very high-frequency (VHF) sound at low power levels, short pulse lengths, and narrow beamwidths. Because output from these sound sources would attenuate to below any current threshold for marine species at very short range, and they are under positive control of the diver on which direction the sonar is pointed, marine species reaction are not likely. No additional quantitative modeling is required for marine species that might encounter these sound sources.
Doppler Sonar/Speed Logs Navigation equipment, downward-focused, narrow beamwidth, HF/VHF spectrum utilizing very short pulse lengths.	DS2, DS3, DS4	Marine species are expected to exhibit no more than short-term and inconsequential responses to the sonar, profiler, or pinger, given their characteristics (e.g., narrow, downward-directed beam), which is focused directly beneath the platform. Such reactions are not considered to constitute "taking". Therefore, no additional quantitative modeling is required for marine species that might encounter these sound sources.
Imaging Sonar (IMS) HF or VHF, very short pulse lengths, narrow bandwidths. IMS1 is a side-scan sonar (HF/VHF, narrow beams, downward-directed). IMS2 is a downward-looking source, narrow beam, and operates above 180 kHz (basically a fathometer).	IMS1, IMS2	These side-scan sonars operate in a VHF range (over 120 kHz) relative to marine mammal hearing (Richardson et al., 1995; Southall et al., 2007). The frequency range from these side-scan sonars is beyond the hearing range of mysticetes (baleen whales) pinnipeds, manatees, and sea turtles. Therefore, they are not expected to affect these species in the Study Area. The frequency range from these side-scan sonars falls within the upper end of odontocete (toothed whale) hearing spectrum (Richardson et al., 1995), which means that they are not perceived as loud acoustic signals with frequencies below 120 kHz by these animals. Therefore, marine species may be less likely to react to these types of systems in a biologically significant way. Further, in addition to spreading loss for acoustic propagation in the water column, HF acoustic energies are more quickly absorbed through the water column than sounds with lower frequencies (Urick, 1983). Additionally, these systems are generally operated in the vicinity of the sea floor, thus reducing the sound potential of exposure even more. Marine mammals are expected to exhibit no more than short-term and inconsequential responses to the imaging sonar given their characteristics (e.g., narrow, downward-directed beam and short pulse length "generally 20 msec"). Such reactions are not considered to constitute "taking". Therefore, no additional quantitative modeling is required for marine species that might encounter these sounds sources.

Table 4. Non-Impulsive Sources Utilized in the Study Area but Not Quantitatively Analyzed (Cont'd)

Source Class Category	Source Class	Description
HF Acoustic Modems (M) and Tracking Pingers (P)	M2, P1, P2, P3, P4	Acoustic modems and tracking pingers operate at frequencies between 2 and 170 kHz, have low duty cycles (single pings in some cases), short pulse lengths (typically 20 milliseconds), and relatively low source levels. Marine species are expected to exhibit no more than short-term and inconsequential responses to these systems given the characteristics described above. Such reactions are not considered to constitute "taking". Therefore, no additional quantitative modeling is required for animals that might encounter these sound sources.
Acoustic Releases (R) Systems that transmit active acoustic signals to release a bottom-mounted object from its housing in order to retrieve the device at the surface.	R1, R2, R3	Acoustic releases operate at MF and HF. Because these types of devices are only used to retrieve bottom-mounted devices, they typically transmit only a single ping. Marine species are expected to exhibit no more than short-term and inconsequential responses to these sound sources given that any sound emitted is extremely short in duration. Such reactions are not considered to constitute "taking". Therefore, no additional quantitative modeling is required for marine species that might encounter these sound sources.
Side-Scan Sonars (SSS) Sonars that use active acoustic signals to produce high-resolution images of the seafloor.	SSS1, SSS2, SSS3	Marine species are expected to exhibit no more than short-term and inconsequential responses to these systems given the system characteristics such as a downward-directed beam and use of short pulse lengths (less than 20 msec). Such reactions are not considered to constitute "taking". Therefore, no additional quantitative modeling is required for marine species that might encounter these sound sources.
Small Impulsive Sources	Sources with explosive weights less than 0.1 lb net explosive weight (less than bin E1)	Quantitative modeling in multiple locations has validated that these low-level impulsive sources are expected to cause no more than short-term and inconsequential responses in marine species due to the low explosive weight and corresponding very small zone of influence associated with these types of sources.

Modern sonar technology includes a multitude of sonar sensor and processing systems that fall within the designation of non-impulsive sound sources. The Navy utilizes sonars and other acoustic sensors in support of many mission requirements, including detection and classification of submarines and mines, localization and tracking of targets, safe navigation, underwater communications, and oceanographic surveys.

All sounds, including sonar, are categorized by frequency. For the GOA Supplemental EIS/OEIS, active sonar is categorized into four frequency ranges: low-frequency (LF), MF, HF, and VHF.

- LF active sonar emits sounds at frequencies less than or equal to 1 kHz.
- MF active sonar emits sounds at frequencies greater than 1 to 10 kHz.
- HF active sonar emits sounds at frequencies greater than 10 to 100 kHz.

- VHF active sonar emits sounds at frequencies greater than 100 to 200 kHz. Sources operated at frequencies above 200 kHz are considered to be inaudible and are not analyzed quantitatively.

4.5 SOUND SOURCE DATA

All sound source parameters relevant to the modeling were archived in a Navy Sound Source Data file. Given its central importance, the Navy Sound Source Data file was controlled for modification and was also subject to revision control. This process ensured that consistent sets of sound source data were used throughout all simulations. The current version of the Navy Sound Source Data file used for Phase II modeling was archived on a data server for universal access. The nature of the acoustic source data parameters dictated that these files were classified at the highest classification level associated with any of the acoustic source entries. Figures 5 and 6 provide an unclassified segment of an impulsive and a non-impulse Navy Sound Source Data file. Column headings relevant to impulsive sources that are different from the non-impulsive source headings are shown in red font.

Each line in the Navy Sound Source Data file represents a unique acoustic source and mode. It was constructed on a platform basis, such that all sources and their associated modes were grouped with the relevant platform. This resulted in duplication of sources in some cases, but the benefit was the complete grouping on a per platform basis. For example, a guided missile destroyer and a frigate might have several systems in common, such as a towed array, a fathometer, and a pinger, each of which would be associated with the respective platform. The benefit of being able to readily see a complete set of modeled source and mode assignments far outweighed the fact that certain system entries were duplicated. The Navy Sound Source Data file also played an important role in repeatability and standardization by providing a mechanism to ensure that acoustic sources were modeled with the same parameters, regardless of who actually performed the modeling.

!UNCLASSIFIED	8	3															
#Platform Type	Platform Name	Source Type	Source Name	Bin Name	Mode Name	Active Time	Depth	NEW	Min Impact Range	Max Impact Range	Pulse Interval	Number of Points	Horizontal Beam Width	Vertical Beam Width	DE Angle	NEW	Max Propagation Radius
#Units						secs	m	kg	m	m	secs		degs	degs	degs	lbs	m
Explosive	Projectile	Explosive	8 mm	E1	Explosive	t1	d1	new	min	max	pi1	#	hbw1	vbw1	de1	new	mpr1

Figure 5. Example of an Impulsive Sound Source Data File

!UNCLASSIFIED	8	3															
#Platform Type	Platform Name	Source Type	Source Name	Mode Type	Mode Name	Active Time	Depth	Source Level	Low Freq	High Freq	Pulse Interval	Pulse Length	Horizontal Beam Width	Vertical Beam Width	DE Angle	Relative Beam Angle	Max Propagation Radius
#Units						secs	m	dB	Hz	Hz	secs	millisecs	degs	degs	degs	degs	m
Helo	SH60B	Dip Sonar	ALFS	Search	Search	t2	d2	l2	f2_l	f2_h	pi2	pl2	hbw2	vbw2	de2	rba2	mpr2
Sonobuoy	AN_SSQ-86	Transducer	DLC	Search	Search	t3	d3	l3	f3_l	f3_h	pi3	pl3	hbw3	vbw3	de3	rba3	mpr3
Source	Generic	Pinger	DPSK	K	K	t4	d4	l4	f4_l	f4_h	pi4	pl4	hbw4	vbw4	de4	rba4	mpr4
Source	Generic	Puts	PUTS	Reply	Reply	t5	d5	l5	f5_l	f5_h	pi5	pl5	hbw5	vbw5	de5	rba5	mpr5
Submarine	688i	Sonar	BQQ-5	Search	Search	t6	d6	l6	f6_l	f6_h	pi6	pl6	hbw6	vbw6	de6	rba6	mpr6
Surface Ship	DDG - ASW	MF Sonar	SQS-53C	Search	VD	t7	d7	l7	f7_l	f7_h	pi7	pl7	hbw7	vbw7	de7	rba7	mpr7
Target	MK 30	Pinger	Pinger	Tracking	Tracking	t8	d8	l8	f8_l	f8_h	pi8	pl8	hbw8	vbw8	de8	rba8	mpr8
Torpedo - HW	MK48	Sonar	Sonar	Search	Search	t9	d9	l9	f9_l	f9_h	pi9	pl9	hbw9	vbw9	de9	rba9	mpr9
Torpedo - LW	MK46	Sonar	Sonar	Search	Search	t10	d10	l10	f10_l	f10_h	pi10	pl10	hbw10	vbw10	de10	rba10	mpr10

Figure 6. Example of a Non-Impulsive Sound Source Data File

5. MARINE SPECIES EFFECTS CRITERIA

Criteria and thresholds have been developed to quantify the potential effects of Navy-generated sound on marine species. Criteria are metrics that identify the potential categories of effects on marine species, such as mortality or temporary physiological effects. Thresholds are the numerical values associated with each criterion. Separate criteria and thresholds have been developed for impulsive and non-impulsive sources. The GOA Supplemental EIS/OEIS and Finneran and Jenkins (2012) provide details on the derivation of the weighting curves and the criteria/thresholds.

5.1 FREQUENCY WEIGHTING

Frequency-weighting functions, called M-weighting functions, were proposed by Southall et al. (2007) to account for the frequency bandwidth of hearing in marine mammals. Frequency-weighting functions are used to adjust the received sound level based on the sensitivity of the animal to the frequency of the sound. Two sets of weighting functions were used in developing thresholds for effects on marine mammals and sea turtles from impulsive and non-impulsive sounds (figures 7 and 8). An explanation of these functions can be found in Finneran and Jenkins (2012).

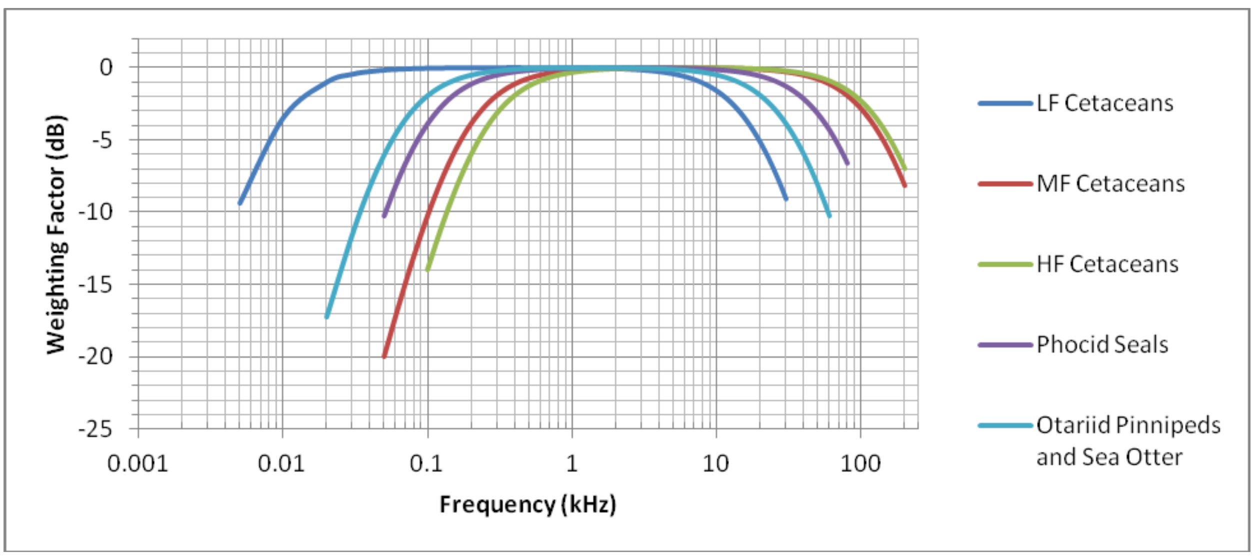

Figure 7. Navy Type I Weighting Functions

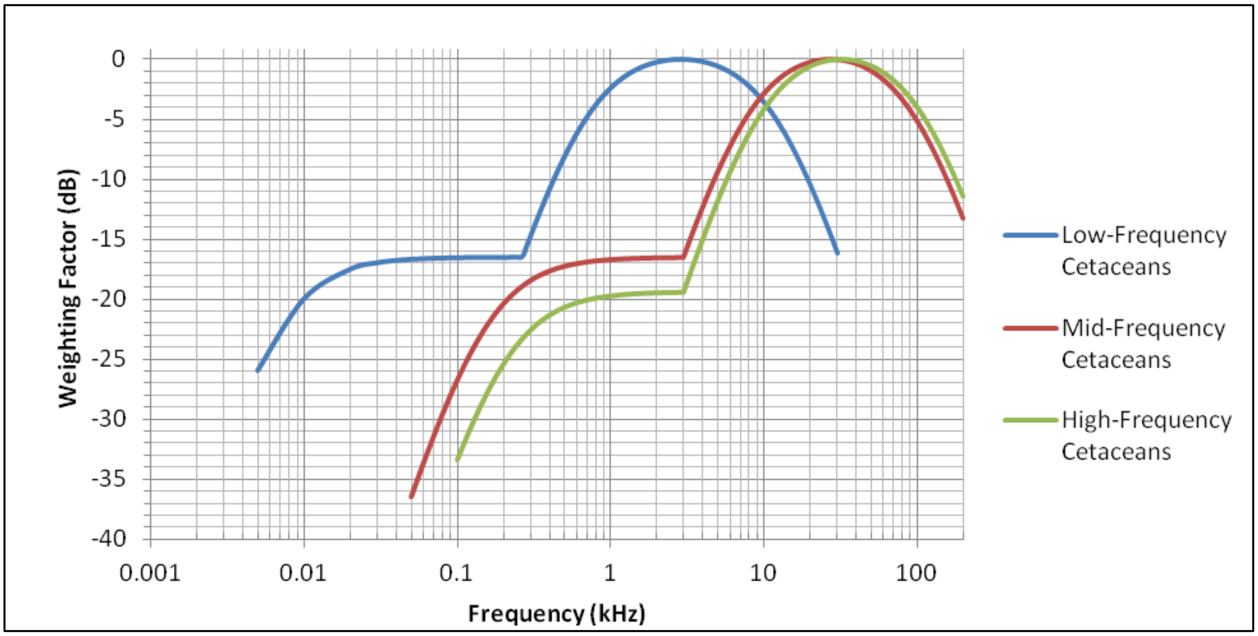

Figure 8. Navy Type II Weighting Functions for LF, MF, and HF Cetaceans

5.2 IMPULSIVE CRITERIA AND THRESHOLDS

Two types of impulsive criteria and thresholds have been generated: one for explosive sources and one for pile driving and air guns. For underwater detonations, five criteria have been developed: (1) onset mortality and onset slight lung injury, (2) onset slight gastrointestinal tract injury, (3) onset permanent threshold shift (PTS), (4) onset temporary threshold shift (TTS), and (5) behavioral effect.

1. Onset Mortality and Onset Slight Lung Injury – Criteria based on impulse. Thresholds for these two criteria are species dependent, as evaluated by equations (2) and (3):

$$\text{Onset mortality} = 91.4 M^{1/3}\left(1+\frac{D_{Rm}}{10.081}\right)^{1/2} Pa-\text{sec}, \qquad (2)$$

where, M is the animal mass (kg) and D_{Rm} is the mammal depth (m).

$$\text{Onset slight lung injury} = 39.1 M^{1/3}\left(1+\frac{D_{Rm}}{10.081}\right)^{1/2} Pa-\text{sec}, \qquad (3)$$

where, M is the animal mass (kg) and D is the animal depth (m).

2. Onset of Slight Gastrointestinal Tract Injury – Criterion based on peak sound pressure level (SPL). Threshold is independent of species and is evaluated as a peak SPL of 237 dB re 1 µPa for all species.

3. Onset of Permanent Threshold Shift – Dual criteria based on sound exposure level (SEL) and peak SPL. Dual criteria means that the animal is determined to experience the onset of PTS when either threshold is exceeded, but not necessarily both. Thresholds associated with these criteria are species dependent and are provided in table 5.

4. Onset of Temporary Threshold Shift – Dual criteria based on SEL and peak SPL. Thresholds associated with these criteria are species dependent and are 15 dB lower than PTS thresholds, as provided in table 5.

5. Behavioral Effect – Criterion based on SEL. Thresholds associated with these criteria are species dependent and are provided in table 5. This criterion is only considered when an animal experiences multiple detonations within a 24-hour period.

For pile driving activities, two criteria have been adopted from the National Marine Fisheries Service (FR 73(53):14447): (1) injury and (2) disturbance. Both criteria are based on SPL and are defined in table 5. Pile driving was not modeled within NAEMO and is only included in the table below for reference.

Table 5. Impulsive Criteria and Thresholds for Marine Species

Group	Species	Onset Mortality	Onset Slight Lung Injury	Onset Slight GI Tract Injury	Onset PTS	Onset TTS	Behavioral (for ≥2 pulses/24 hr)	Non-Explosive Impulsive Source (NMFS Level A)	Non-Explosive Impulsive Source (NMFS Level B)
LF Cetaceans	All mysticetes	Note 1	Note 2	237 dB SPL (104 psi)	187 dB SEL (Type II weighted) or 230 dB Peak SPL	172 dB SEL (Type II weighted) or 224 dB Peak SPL	167 dB SEL (Type II weighted)	180 dB SPL_{RMS}[3]	160 dB SPL_{RMS}
MF Cetaceans	Most delphinids, beaked whales, medium and large toothed whales				187 dB SEL (Type II weighted) or 230 dB Peak SPL	172 dB SEL (Type II weighted) or 224 dB Peak SPL	167 dB SEL (Type II weighted)	180 dB SPL_{RMS}	160 dB SPL_{RMS}
HF Cetaceans	Porpoises, River dolphins, *Cephalorynchus* spp., *Kogia* spp.				161 dB SEL (Type II weighted) or 201 dB Peak SPL	146 dB SEL (Type II weighted) or 195 dB Peak SPL	141 dB SEL (Type II weighted)	180 dB SPL_{RMS}	160 dB SPL_{RMS}
Phocidae Water	All phocid seals				192 dB SEL (Type I weighted) or 218 dB Peak SPL	177 dB SEL (Type I weighted) or 212 dB Peak SPL	172 dB SEL (Type I weighted)	190 dB SPL_{RMS}	160 dB SPL_{RMS}
Otariidae & Obodenidae Water	Sea lions, Fur seals, and Walruses				215 dB SEL (Type I weighted) or 218 dB Peak SPL	200 dB SEL (Type I weighted) or 212 dB Peak SPL	195 dB SEL (Type I weighted)	190 dB SPL_{RMS}	160 dB SPL_{RMS}
Mustelidae Water	Sea Otters							190 dB SPL_{RMS}	160 dB SPL_{RMS}
Ursidae Water	Polar Bears							190 dB SPL_{RMS}	160 dB SPL_{RMS}
Sirenia	Manatees and Dugongs				192 dB SEL (Type I weighted) or 218 dB Peak SPL	177 dB SEL (Type I weighted) or 212 dB Peak SPL	172 dB SEL (Type I weighted)	190 dB SPL_{RMS}	160 dB SPL_{RMS}
Sea Turtles (Chelonioidea)	Sea Turtles	Note 1	Note 2	237 dB SPL (104 psi)	187 dB SEL (Type I weighted) or 230 dB Peak SPL	172 dB SEL (Type I weighted) or 224 dB Peak SPL	160 dB SEL (Type I weighted)	190 dB SPL_{RMS}	160 dB SPL_{RMS}

Note 1: $=91.4M^{1/3}\left(1=\frac{D_{Rm}}{10.081}\right)^{1/2} Pa-\sec$, where M = mass of animals in kg and D_{Rm} = depth of receiver (animal) in meters.

Note 2: $=39.1M^{1/3}\left(1+\frac{D_{Rm}}{10.081}\right)^{1/2} Pa-\sec$, where M = mass of animals in kg and D_{Rm} = depth of receiver (animal) in meters.

Note 3: RMS refers to 90% of the energy under the envelope, per NMFS Office of Protected Resources.

5.3 NON-IMPULSIVE CRITERIA AND THRESHOLDS

NAEMO can record every ping received by every animat in a given scenario. However, because animals cannot hear at all frequencies, certain pings are ignored if they fall outside an animal's hearing range. The Navy has adopted a single frequency cutoff at each end of a functional hearing group's frequency range, based on the most liberal interpretations of their composite hearing abilities. These cutoffs, called boxcar frequencies, exceed the demonstrated or anatomy-based hypothetical upper and lower limits of hearing within each group. Table 6 provides the lower and upper frequency limits for each species group. Sounds with frequencies below the lower frequency limit, or above the upper frequency limit, are not analyzed with respect to auditory effects for a particular group.

Table 6. Boxcar Frequencies Implemented in the Navy Acoustic Effects Model

Species Group	Limit (Hz)	
	Lower	Upper
LF Cetaceans	5	30,000
MF Cetaceans	50	200,000
HF Cetaceans	100	200,000
Otariid Pinnipeds, Walruses, Sea Otters, Polar Bears (in water)	20	60,000
Phocid Pinnipeds, Sirenians (in water)	50	80,000
Sea Turtles (in water and air)	5	3000

For non-impulsive sources, three criteria have been developed: (1) PTS, (2) TTS, and (3) behavioral effects.

5.3.1 Permanent Threshold Shift and Temporary Threshold Shift

PTS and TTS criteria are based on SEL, which requires the accumulation of energy from every ping within each of four frequency bands over a 24-hour period. Energy is accumulated within the following four frequency bands: LF, MF, HF, and VHF.

After the energy has been summed within each frequency band, the band with the greatest amount of energy is used to evaluate the onset of PTS for each species; the thresholds for each species group are provided in table 7. Animals that have not yet been accounted for in PTS are then considered for TTS if the accumulated energy is above thresholds as defined in table 7.

Table 7. Non-Impulsive Criteria and Thresholds for Marine Species

<table>
<tr><th rowspan="2">Group</th><th rowspan="2">Species</th><th colspan="2">Physiological Criteria</th><th rowspan="2">Behavioral Criteria</th></tr>
<tr><th>Onset PTS</th><th>Onset TTS</th></tr>
<tr><td>LF Cetaceans</td><td>All mysticetes</td><td>198 dB SEL
(Type II weighted)</td><td>178 dB SEL
(Type II weighted)</td><td>Mysticete Dose Function
(Type I weighted)</td></tr>
<tr><td>MF Cetaceans</td><td>Most delphinids, beaked whales, medium- and large-toothed whales</td><td>198 dB SEL
(Type II weighted)</td><td>178 dB SEL
(Type II weighted)</td><td>Odontocete Dose Function
(Type I weighted)</td></tr>
<tr><td>Beaked Whales</td><td>All Ziphiidae</td><td>See MF cetacean criterion</td><td>See MF cetacean criterion</td><td>140 dB SPL, unweighted</td></tr>
<tr><td>HF Cetaceans</td><td>Porpoises, River dolphins, Cephalorynchus spp., Kogia spp.</td><td rowspan="2">172 dB SEL
(Type II weighted)</td><td rowspan="2">152 dB SEL
(Type II weighted)</td><td>Odontocete Dose Function
(Type I weighted)</td></tr>
<tr><td>Harbor Porpoises</td><td>Harbor Porpoises</td><td>120 dB SPL, unweighted</td></tr>
<tr><td>Phocidae
(in water)</td><td>Harbor, Bearded, Hooded, Common, Spotted, Ringed, Baikal, Caspian, Harp, Ribbon, Gray seals, Monk, Elephant, Ross, Crabeater, Leopard, and Weddell seals</td><td>197 dB SEL
(Type I weighted)</td><td>183 dB SEL
(Type I weighted)</td><td>Odontocete Dose Function
(Type I weighted)</td></tr>
<tr><td>Otariidae and Odobenidae
(in water)</td><td>Sea lions, Fur seals, and Walruses</td><td rowspan="3">220 dB SEL
(Type I weighted)</td><td rowspan="3">206 dB SEL
(Type I weighted)</td><td rowspan="3">Odontocete Dose Function
(Type I weighted)</td></tr>
<tr><td>Mustelidae
(in water)</td><td>Sea Otters</td></tr>
<tr><td>Ursidae
(in water)</td><td>Polar Bears</td></tr>
<tr><td>Sirenia</td><td>Manatees and Dugongs</td><td>197 dB SEL
(Type I weighted)</td><td>183 dB SEL
(Type I weighted)</td><td>Odontocete Dose Function
(Type I weighted)</td></tr>
<tr><td>Sea Turtles
(Chelonioidea)</td><td>Sea Turtles</td><td>198 dB SEL
(Type I weighted)</td><td>178 dB SEL
(Type I weighted)</td><td>175 dB SPL
(Type I weighted)</td></tr>
</table>

5.3.2 Behavioral Effects

Behavioral effects have a single criterion based on an animal's maximum received SPL. SPL is evaluated in the same frequency bands as those for SEL. Behavioral risk functions are applied to the maximum weighted SPL in each frequency band, though the MF dose-response curve is used for all frequency bands. The highest number of behavioral takes in any frequency band listed in section 4.4 is recorded for that species. Harbor porpoises are evaluated for behavioral effects using a step function at 120 dB, beaked whales using a step function at 140 dB, and sea turtles using a step function at 175 dB. An animal is evaluated for behavioral effects only if neither TTS nor PTS has been calculated for that animal.

6. NAEMO ANALYSIS PROCESS

This section describes the process of using the basic scenario descriptions provided by the scenario working group to generate the information and data required to execute the NAEMO software and ultimately produce the estimated effects on marine species. The process begins with the creation of the scenario entry worksheets and continues through each of the seven NAEMO modules and ends with the creation of estimated effects tables. Each of the following sections provides an overview of each step in this process; moreover, each section identifies the major inputs required and output produced along with any assumptions made.

6.1 SCENARIO ENTRY WORKSHEET

A Scenario Entry Worksheet was developed to document scenario details required by NAEMO. The Scenario Entry Worksheet facilitated the process of recording and authenticating important modeling inputs and was used for all Phase II events. The worksheet also ensured standardization and repeatability for this fundamental data entry part of the process. An example of a Scenario Entry Worksheet is provided in figure 9.

6.2 SCENARIO BUILDER

Scenario Builder (figure 10) is the fundamental building block of the NAEMO software and is used to input a scenario described on the Scenario Entry Worksheet. Scenario Builder input are stored in files that are used by all other NAEMO modules. Information stored in the files includes what platforms are participating in the scenario, what sources are used, where it will occur, the duration of the scenario, and when (e.g., which season) it would occur. A scenario definition may involve a single platform with one or more sound sources or multiple platforms, each with single or multiple sound sources.

Each scenario builder file represents the activities from a single modeling location and season. Scenarios occurring in multiple locations or seasons require generating multiple Scenario Builder files, a process that can easily be conducted from within Scenario Builder. Similarly, multiple scenario input files are needed to define scenario events that occur over multiple days. Each file represents the activities over one 24-hour window of time. Each file is classified as a scenario sub-event, and any number of sub-events can be defined.

Cumulative effects from scenarios that occur over multiple days or sub-events are computed in the Report Generator module. Additional details on how this was done can be found in the Report Generator section.

Scenario events involving sources from multiple source categories (e.g., impulsive and non-impulsive) require multiple scenario descriptions. Each scenario includes all platforms and sources from a single source category. No accumulation of effects between scenarios involving different source categories is considered due to the different metrics used for each of the criteria thresholds.

Scenario ID	SC1_GOA
Scenario Name	Scenario 1 Name
Customer Entity/POC	CPF / Joe N. Ginere
Created By	
Checked By	
Ready For Modeling (y/n)	

Worksheet classification		
Unclass.	Conf.	Secret
X		

Event									
Number	Name	Description	Month or Season	Duration (hrs)	Operational Boundary: Center Lat	Operational Boundary: Center Long	Operational Boundary: Length (km)	Operational Boundary: Width (km)	Range Complex (i.e., OPAREA)
1	SC1_AREA1_WARM	Surface Ship ASW	Warm	10.0	Area 1				GOA
2	SC1_AREA2_WARM			10.0	Area 2				
3	SC1_AREA1_COLD	Surface Ship ASW	Cold	10.0	Area 1				GOA
4	SC1_AREA2_COLD			10.0	Area 2				

Duplicate the following for all other locations

Platform: Type	Name	Number	Launch Platform for stand-alone sources (if applicable)	Geometry: Track Type	Geometry: Scripted (*describe*)	Geometry: Speed (knots)	Geometry: Depth (m)	Source (per platform): Name	Mode (per platform): Name	Mode (per platform): No. of Pings or Duration (hrs)	NOTES / COMMENTS / ASSUMPTIONS
Surface Ship	CVN	1	n/a	Perimeter Bounce	n/a	25	0	Fathometer	Fathometer	10.0	All numbers are fictional.
								NIXIE	Broadband	10.0	
Surface Ship	DDG (ASW)	3	n/a	Perimeter Bounce	n/a	12	0	SQS-53C	VD/SD	10.0	All numbers are fictional.
								Fathometer	Fathometer	10.0	
								NIXIE	Broadband	10.0	
Submarine	*Virginia*	1	n/a	Perimeter Bounce	n/a	10	100	BQQ-10	Search	1 source	All numbers are fictional.
								Sail Array	Search	1 source	
		1	n/a	Perimeter Bounce	n/a	10	200	BQQ-10	Search	1 source	
								Sail Array	Search	1 source	
Counter-measure	ADC	1	n/a	Stationary	n/a	0	100	ADC	Broadband	default	All numbers are fictional.
		1	n/a	Stationary	n/a	0	200	ADC	Broadband	default	
Aircraft	Helo	6	n/a	Stationary	n/a	0	100	AQS-22	Search	1 source	All numbers are fictional.
Sonobuoy	DICASS	18	n/a	Stationary	n/a	0	100	DICASS	Search	default	All numbers are fictional.
		18					200	DICASS	Search	default	
		18					300	DICASS	Search	default	

Figure 9. Example Scenario Entry Worksheet

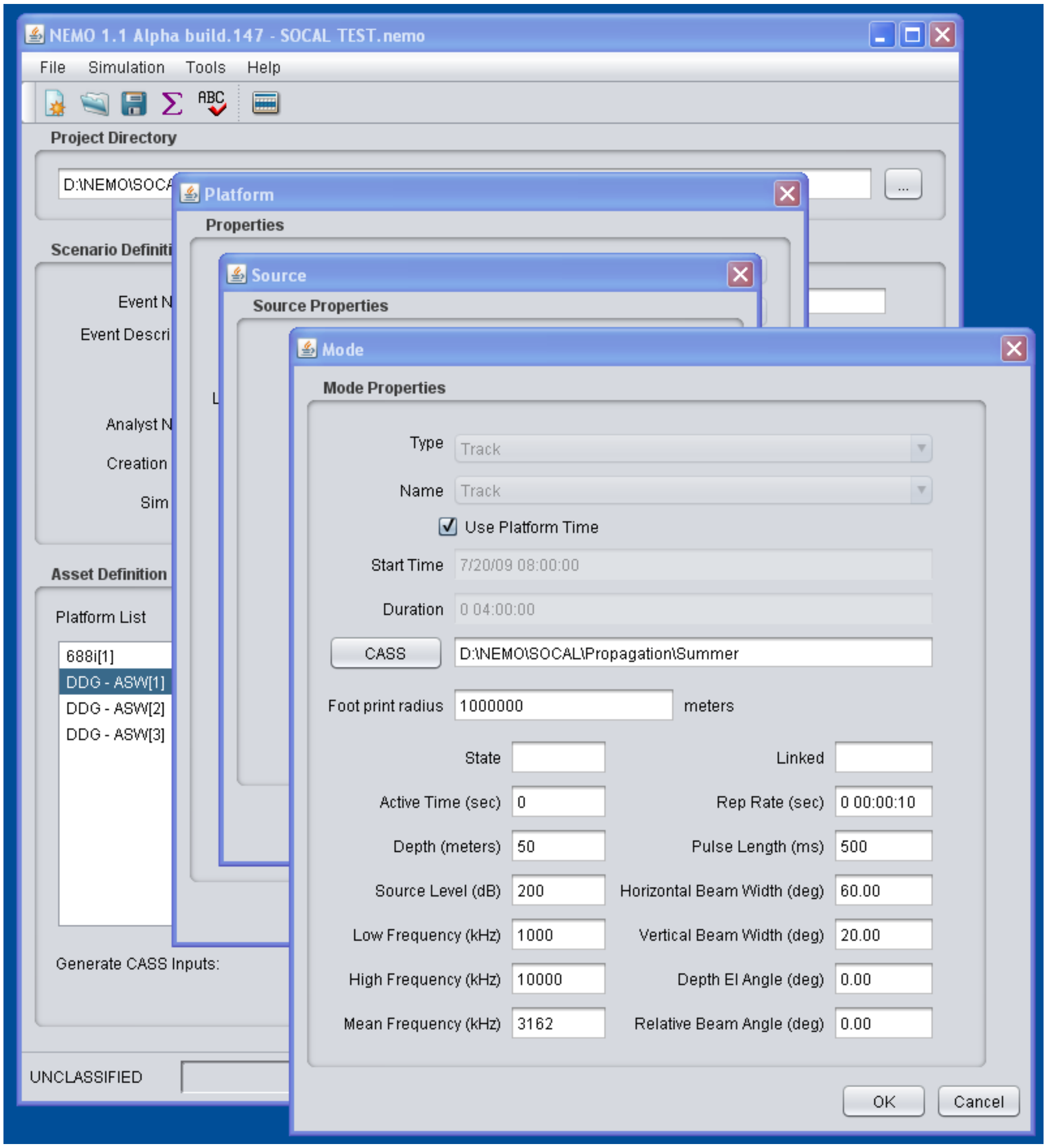

Figure 10. Example Scenario Builder Screen

Scenario Builder is a GUI that contains multiple panels. Each panel is organized by the type of information being defined. The initial panel allows for the definition of global scenario parameters, such as event description and duration, season, and simulation area, along with some user and computer system specific data. This information is archived in the Scenario Builder input file along with all of the scenario-specific information.

Adding a platform to the scenario is completed by selecting the add platform button on the main panel. This opens the platform definition panel, which contains a list of available platforms to choose from. The list of available platforms is generated from the Navy Sound Source Data file. Once a platform is selected for inclusion in a scenario, all of its associated sound sources are displayed in the Sound Source panel. The user then has the option to choose the sources relevant to the scenario of interest; moreover, the user could readily add or delete a source at this stage. For example, a surface ship was defined as a platform with several default sources that could be activated, such as hull-mounted and towed sonar. Impulsive and non-impulsive source parameters for all selected sources can be viewed in the Sound Source Mode panel. These parameters are also extracted from the Navy Sound Source Data file and cannot be edited from within Scenario Builder. This process helps to ensure that a standard set of impulsive or non-impulsive source parameters are being used throughout all simulations. Additional platforms can be added by selecting the Add Platform button multiple times.

Within Scenario Builder, platform depth and movement through the environment was defined using the Track Panel. Platform movement was defined by either a predefined or random track or a stationary location. In the random mode, vehicle track was initiated at a randomly selected course starting at a randomly selected location within the track box defined for that event. The vehicle then moved at its prescribed speed along this track until it reached the boundary of the track box, where the platform bounced off the track boundary in accordance with the rules for specular reflection, namely, equal angle of incidence and reflection bounces (figure 11). This process was repeated for the duration of the event as defined in the Scenario Entry Worksheet. A stationary location was defined, either as a known latitude and longitude location or as a randomly selected location within the defined track box associated to this scenario. Phase II modeled events for GOA were characterized by random tracks, which allow for variability of ship tracks, variability between events, and variability in environmental conditions that affect tactics associated with an event.

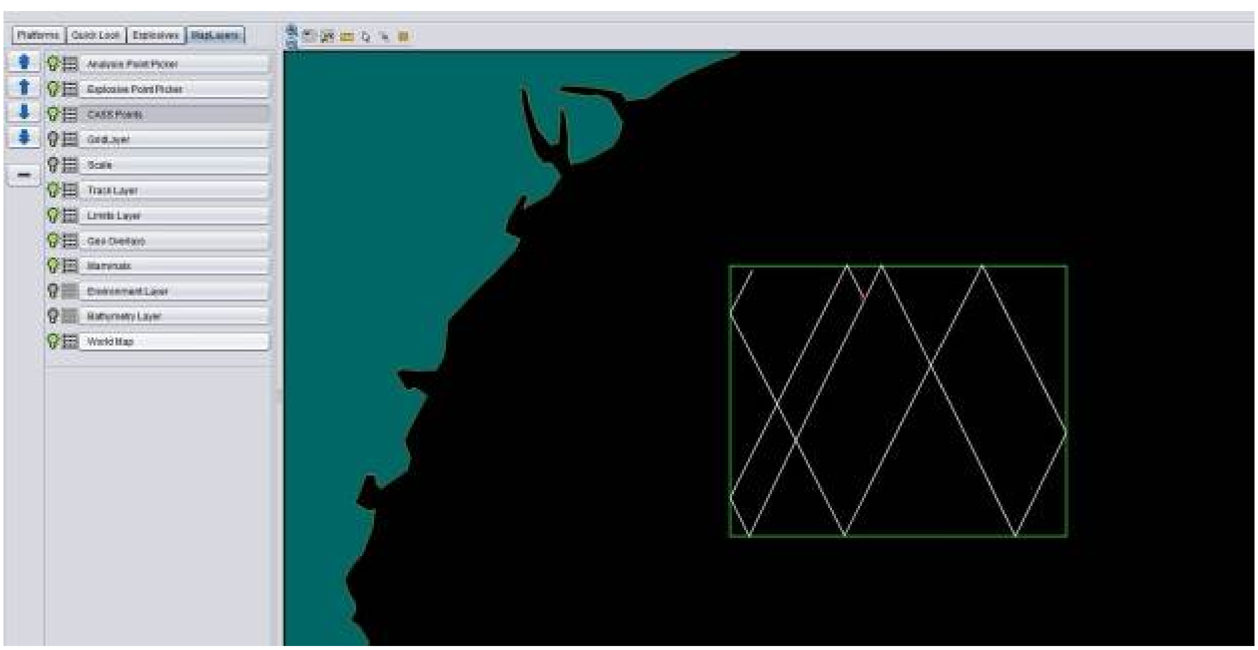

Figure 11. Example Perimeter Bounce

Stationary platforms were typically used for modeling events with platforms that operated in a fixed location for a period of time. An example of a platform with a stationary source is the helicopter dipping sonar system. Each time the helicopter deployed the dipping sonar system, it was modeled in a fixed location for a fixed amount of time. If the scenario defined the helicopter conducting multiple dips, each dip was modeled in a randomly selected location within the modeling box. Other systems modeled in this manner included sonobuoys, bottom-mounted sensors, and impulsive sources.

Scenario Builder also provides a mechanism to define when and how long each non-impulsive sound source is active during the simulation by sound source mode, sound source, platform, or event duration.

Clustering associated with impulsive sources was also defined within Scenario Builder. Clustering is defined as a series of impulsive sources that are detonated within a short period of time so as to act as a single impulsive event. An example of a clustered system is a burst of automatic gun fire from a gun mounted on a surface ship or aircraft. Multiple clusters would be defined in a similar manner as multiple single-impulsive sources.

6.3 ENVIRONMENT BUILDER

Since accurate *in-situ* measurements cannot be used to model activities that occur in the future, historical data must be used for these propagation loss calculations. Propagation loss ultimately determines the extent of the area in which effects to marine mammals and sea turtles are possible for a particular activity. Spreading and absorption are significant factors that determine propagation loss. In addition to the acoustic properties, propagation loss as a function of range also depends on a number of environmental parameters including water depth, sound speed profile, bottom geo-acoustic properties, and surface roughness, as determined by wind speed.

This section discusses the relative impact of these various environmental parameters, which can vary both spatially and temporally. Spatial changes are accommodated by using the highest available resolution data from historical databases. Temporal changes are captured by using seasonal definitions.

Within a typical range complex, the environmental parameter that tends to vary the most is bathymetry. It is not unusual for water depths to vary by an order of magnitude or more, resulting in significant impacts on the propagation calculations. Bottom loss can also change considerably over typical range complexes due to variations in the geological composition of bottom sediment (e.g., a muddy bottom absorbs more energy and a rocky bottom reflects more energy), but its impact on propagation tends to be limited to waters on the continental shelf and the upper portion of the slope. Generally, the primary propagation paths in deep water do not involve any interaction with the bottom. In shallow water, particularly if the sound speed profile directs all propagation paths to interact with the bottom, bottom loss variability can play a larger role.

The spatial variability of the sound speed profiles is generally small within the modeling areas. The presence of a strong oceanographic front is a noteworthy exception to this rule. To a lesser extent, variability in the depth and strength of a surface duct can be of some importance. Because of the importance that propagation loss plays in acoustic activities, the Navy has, over the last four to five decades, invested heavily in measuring and modeling the relevant environmental parameters. The results of this effort are global databases of these environmental parameters that comprise part of the Oceanographic and Atmospheric Master Library (OAML).

These environmental databases are accepted as Navy standards and used in NAEMO. The use of OAML data was a major factor in assuring standardization and repeatability. Some of the databases are classified, and the distribution of OAML data is restricted to organizations within the Department of Defense and its contractors. The versions of the OAML databases within NAEMO are provided in table 8. On the rare occasion OAML data are not available other data are used. This was the case for all modeling done in Puget Sound for which National Oceanic and Atmospheric Administration data were used.

Environment Builder (figure 12) allows for the extraction of oceanographic environmental data required for a scenario simulation, and formats those data appropriately for processing downstream. Based on the selected geographic area, the following data were extracted from an array of points across the region: bathymetry, sound speed profile, wind speed, and bottom properties.

Table 8. Oceanographic and Atmospheric Master Library Environmental Databases

<table>
<tr><th>Parameter</th><th>Database</th></tr>
<tr><td>Bathymetry</td><td>Digital Bathymetric Database Variable-Resolution Version 5.4 (Level 0)</td></tr>
<tr><td>Sound Speed Profile</td><td>Generalized Digital Environmental Model Variable Version 3.01</td></tr>
<tr><td>Wind Speed</td><td>Surface Marine Gridded Climatology Version 2.0</td></tr>
<tr><td rowspan="3">Geo-Acoustic Parameters</td><td>Re-Packed Bottom Sediment Type Version 2.0 (includes HF Environmental Acoustics Version 1.0)</td></tr>
<tr><td>LF Bottom Loss Version 11.1*</td></tr>
<tr><td>HF Bottom Loss Version 2.2*</td></tr>
<tr><td colspan="2">*LF and HF bottom loss databases are used to capture the variability of bottom sediment to absorb or reflect energy from HF and LF sound sources.</td></tr>
</table>

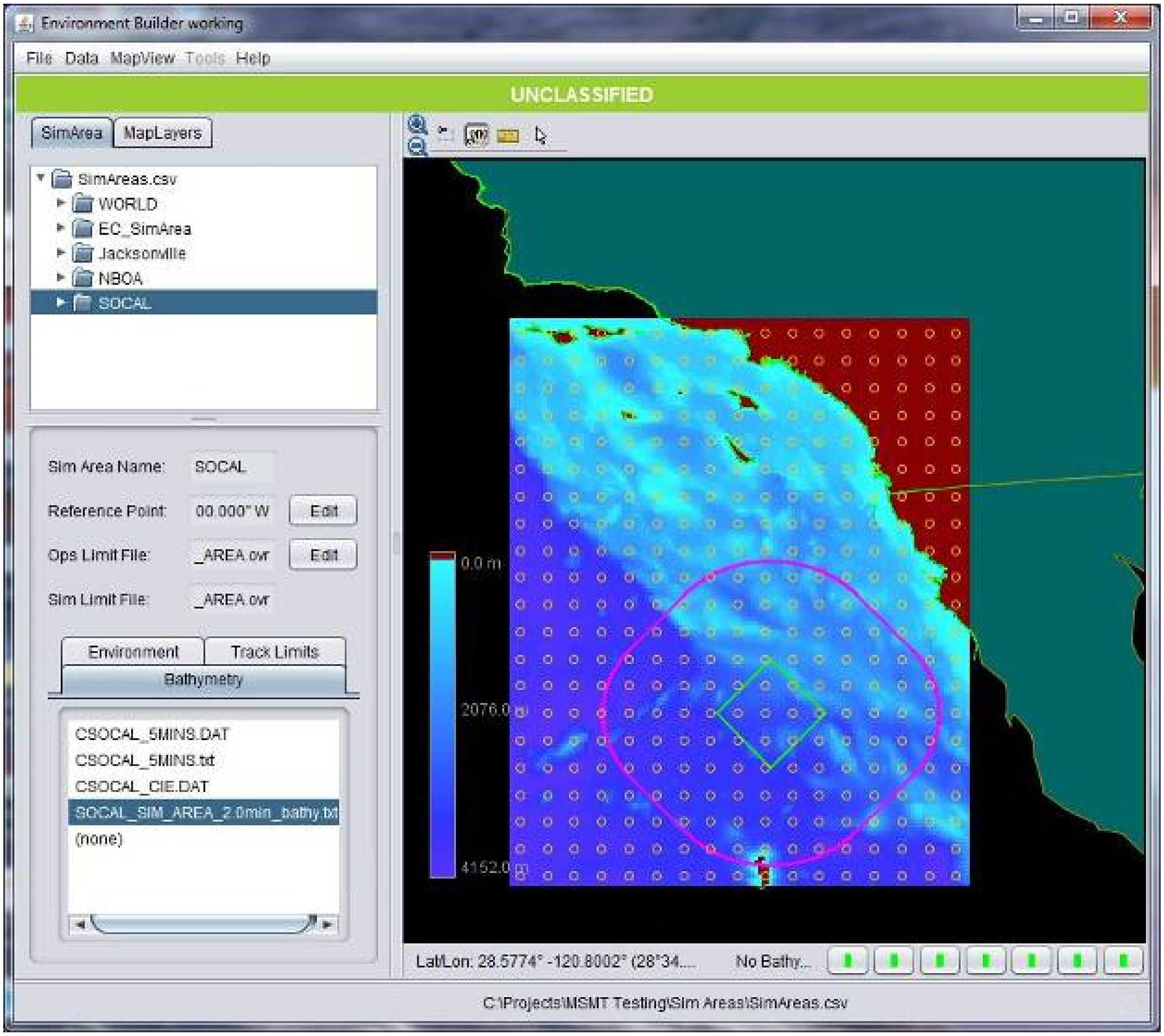

Figure 12. Example Environment Builder Screen

6.3.1 Bathymetry Extraction

CASS software has a 512-kilobyte-size limit for the number of bathymetry data points. Although this limit was not an inherent problem for the quality of the CASS results, it dictated the resolution of the bathymetry data files. For example, smaller areas could be characterized by higher resolution data, whereas large areas required lower resolution data to prevent exceeding the size limit. Typical bathymetry resolution was on the order of half an arc-minute or less.

6.3.2 Sound Speed Profile

Generalized Digital Environmental Model Variable sound speed profile data consist of temperature, salinity, and depth. For each scenario, these data were extracted at the highest resolution, one-quarter degree or 15 arc-minutes, over the extent of the modeled area. The sound speed is calculated with the Chen-Millero-Li sound speed equation (Chen and Millero, 1977).

Figure 13 shows an example of a typical set of sound speed profiles computed from the extracted temperature, salinity, and depth data along a single radial. Typically, sound speed profiles are computed along 20 equally spaced radials ranging from 0-to-360 degrees at multiple locations within the modeling area of interest.

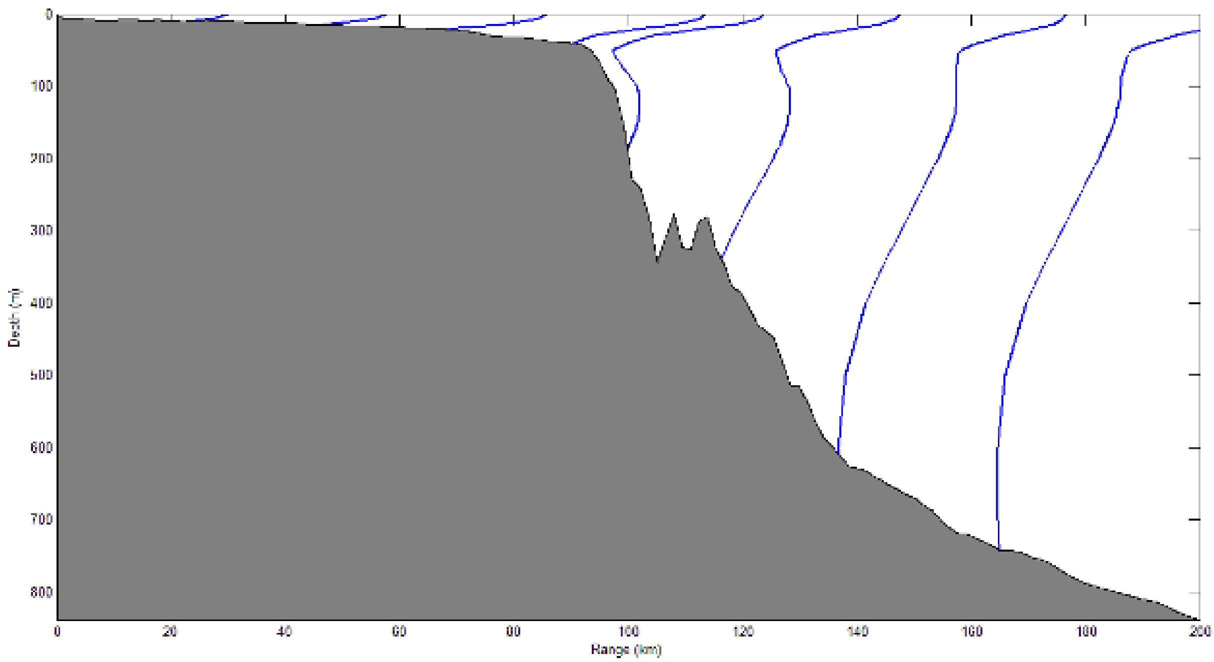

Figure 13. Sample Sound Speed Profile

6.3.3 Wind Speed

All wind speed data were extracted from the Surface Marine Gridded Climatology data at the highest available resolution of one degree. Selection of the best wind speed data is directly related to other environmental parameters, primarily the sound speed. For example, a wind speed introduced in a downward refracting environment would not likely create a significant change in results because of the relatively short propagation ranges characterized by minimal surface interaction. In the case of a surface duct with correspondingly long propagation ranges and associated surface interaction, however, wind speed could have significant impact on the resultant propagation ranges.

6.3.4 Bottom Properties

For each modeled area, bottom type and the associated geo-acoustic parameters were extracted in accordance with the guidelines specified in table 9. These data were extracted at the highest available resolution of one degree.

Table 9. Geo-Acoustic Parameter Guildelines as a Function of Acoustic Source Frequency

Frequency (f)	Database
f < 1 kHz	LF Bottom Loss
1 kHz ≤ f < 1.5 kHz	LF Bottom Loss and HF Bottom Loss
1.5 kHz ≤ f < 4 kHz	HF Bottom Loss
f ≥ 4 kHz	Bottom Sediment Type

6.3.5 Seasonal Definitions

The majority of the Phase II modeling activities within all Navy training and testing areas occur annually and are not normally limited to a specific month or season. For GOA, however, given the likely occurrence of Navy training only during the month of July, July was selected as the seasonal representative for these analyses.

6.4 ACOUSTIC BUILDER

The Acoustic Builder module generates propagation data. It accepts as input the scenario-defining file generated by Scenario Builder and the environmental data files that were extracted with the Environment Builder module and allows the user to define a set of propagation analysis points. These points, along with the required propagation model inputs, were then input into one of the propagation models, and an estimate of the corresponding sound field was generated for each unique source. Once sound field generation was complete, the results were exported to a file that was input to the Scenario Simulator. Considerable intelligence was also built into the Acoustic Builder module to expedite processing and minimize manual analyst intervention.

Three propagation models were used to fulfill the propagation modeling requirements for Phase II analyses. For GOA modeling, only two propagation models were needed: REFMS Version 5.06 was used for impulsive sources and CASS/GRAB Version 4.2a was used for non-impulsive sources. This section provides high-level descriptions of these models and the manner in which they were implemented.

6.4.1 Impulsive Model

REFMS was used for all impulsive modeling. REFMS is a range-independent shock wave model. It uses the properties of an impulsive source and the local environmental parameters to determine distances at which the shock wave, including its associated SPL, SEL, and impulse, dissipates beyond pre-established thresholds for mortality, injury, temporary physiological effects, and behavioral effects to marine species.

Scenario inputs include the depth of the source (surface detonations were modeled at a depth of 1 m), the net explosive weight (in TNT equivalent pounds), the number of sources used in the scenario, and the separation in time and location of sources when multiples are used in a single scenario. For large areas in which an event could occur, a series of analysis points and depths, consistent with the activity’s parameters, are used to adequately represent the locations in which the event could occur. Source depth, munition type and number of detonations are obtained from pull-down menus.

Environmental inputs to REFMS include water depth, bottom sediment properties, and sound speed profiles, all of which are obtained from OAML. For bottom sediment properties, the OAML database was coupled with the Hamilton equations, which provide sound speed ratios for all types of substrata. Wind speed data are not required for impulsive modeling because REFMS does not account for surface loss.

The source locations, as defined in the scenario descriptions, typically identified a modeling box or general area and did not provide exact points where an impulsive event could occur. As such, the analysis points were mapped to the closest one-quarter degree resolution point in the sound speed profiles. Additionally, the depth of the impulsive source was moved to the closest sound speed profile location. If the provided depth was deeper than available in the sound speed profile, the sound speed profile was extrapolated to the depth of the source.

REFMS assumes a uniform, flat bottom throughout the energy field and does not take into account variations in bathymetry. Because of this, the deepest point within a scenario location or the depth at the nearest available environmental data point location was used to preclude animals from being "hidden" beneath the modeled bottom depth. Therefore, they would not be exposed to any energy or sound.

REFMS approximates Cagniard spherical equations (Cagniard, 1962) to calculate distances from the source in which the outputs of total energy, positive impulse, and peak SPL fall below thresholds identified as potential effects to marine species. The Cagniard model used in REFMS is sometimes referred to as "Generalized Ray Theory" in seismology (Spencer, 1960).

Similitude equations calculate constants for each explosive type in terms of TNT equivalents referred to as "similarity parameters for explosives." Britt et al. (1991) indicated that care should be taken in using similitude for small charges. REFMS models the variation of physical properties (i.e., sound speed, shear wave speed, and density) with depth in the ocean water column and at the seafloor. The water column and seafloor are represented with up to 300 homogeneous layers depending on the environment where detonations occur.

The model outputs include positive impulse, SEL (total and in 1/3-octave bands) at specific ranges and depths of receivers (i.e., marine species), and peak pressure. The shock wave consists of two parts, a very rapid onset "impulsive" rise to positive peak over-pressure followed by a reflected negative under-pressure rarefaction wave (figure 14).

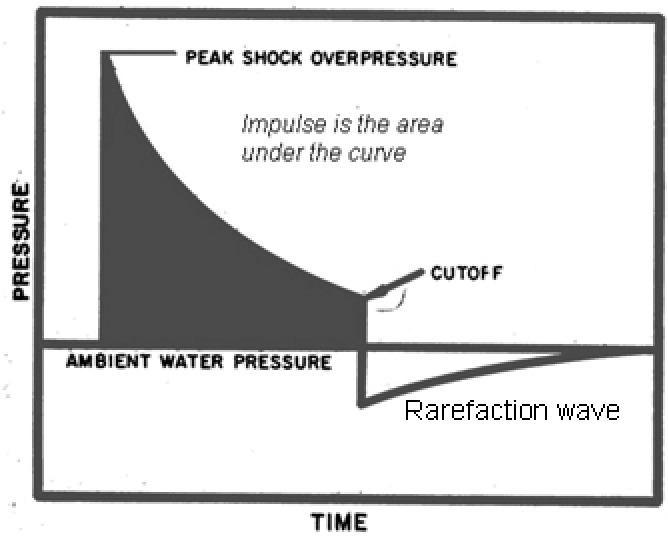

Figure 14. Generalized Shock Wave

The similitude expression for the nonlinear source is given in equations (4) and (5). Equation (5) is generally derived from data; however, the power law can be obtained from weak shock theory. When the nonlinear similitude source is combined with the Cagniard Generalized Ray Theory, a series of transmitted and reflected integrals is given for the various paths (figure 14). In this approach, there is very little dispersion, except for multipath and at the surface or seafloor. In the case of surface rarefaction, positive impulse would be cut off by the reflected wave at the cutoff time.

$P(t)$ provides the pressure-time calculation:

$$P(t) = P_m e - \left(1^{-(t/\theta)}\right), \tag{4}$$

where, θ is the time constant, and the peak over-pressure P_m is given by

$$P_m = K\left(W^{1/3}/R\right)^{\alpha}, \tag{5}$$

where, K and α are constants for particular explosions. Range R to the receiver is determined by ray theoretic equations. The positive impulse is given by the integrated area under the over-pressure wave and is given by $I(t)$ as shown in equation (6):

$$I(t) = \int_0^{\tau} P(t)dt, \tag{6}$$

where the integration interval τ is some multiple of the time constant (Swisdak Jr.,1978).

Propagation of shock waves and sound energy in the shallow-water environment is constrained by boundary conditions at the surface and seafloor (figure 15). A hypothetical source is shown below the sea surface and above the seabed, indicating energy from the explosion reaches a subsurface receiver via multipaths. The iso-speed condition indicates no refraction of paths from changes in sound speed with depth.

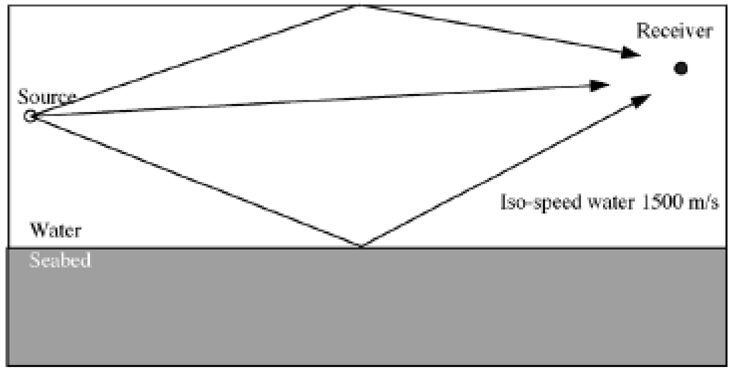

Figure 15. Generalized Pathways of Shock Waves and Sound Energy (Adapted from Siderius and Porter, 2006.)

The propagation sums both direct and secondary reflected and refracted waves at previously defined ranges and depths from the source. The generation of depth points could be modified to account for the deepest dive depth of the marine species populating the simulation area. At each of these range and depth points, the total energy, positive impulse, and peak SPL were calculated to determine the distance at which these metrics fall below thresholds associated with criteria of mortality, injury, temporary physiological effects, and behavioral effects to marine species.

Acoustic Builder features for impulsive sources include:

- For REFMS, an American Standard Code for Information Interchange (ASCII) table was generated for the output parameters as a function of range and depth. Bearing was constant because REFMS output was generated for a single radial (i.e., bearing) only, based on the assumption that the explosion was a spherical release of energy into the water (i.e., omnidirectional).
- To avoid overly thick layers, particularly in the thermocline region, Acoustic Builder is capable of displaying a sound speed profile to verify that the interpolation routine yielded acceptable resolution.
- The capability was provided to be able to change the method of determination of the REFMS depth/range points for the 3-D lookup table output.
- Acoustic Builder limited the generation of depth points based on the deepest dive depth for the marine species populating the simulation area.

6.4.2 Non-Impulsive Models

The CASS/GRAB propagation models were used for all non-impulsive modeling. This model was used in a narrowband analysis mode. Therefore, it was run at a single frequency at a time.

6.4.2.1 CASS/GRAB. The CASS/GRAB model is used to determine the propagation characteristics for all relevant acoustic sources with frequencies greater than 150 Hz. CASS/GRAB is an active and passive range-dependent propagation, reverberation, and signal excess acoustic model; it is part of OAML and has been accepted as the Navy standard and OAML-certified for active sonar analysis between 150 Hz and 500 kHz. Phase II analyses use CASS in the passive propagation mode, that is, one-way propagation, rather than the active mode, which uses two-way propagation. CASS/GRAB uses acoustic rays to represent sound propagation in a medium. As acoustic rays travel through the ocean, their paths are affected by mechanisms such as absorption, reflection, and reverberation, including backscattering, and boundary interaction. The GRAB module accommodates surface and bottom boundary interactions, but does not account for side reflections that would be a factor in a highly reverberant environment, such as a depression or canyon, or in a man-made structure, such as a dredged harbor. Additionally, as with most other propagation models except finite-element-type models, CASS/GRAB does not accommodate diffraction or the propagation of sound around bends.

The CASS/GRAB model determines the acoustic ray paths between the source and a particular location in the water, which is referred to as a “receive cell” in this analysis. The rays that pass through a particular point are called eigenrays. Each eigenray, based on its intensity and phase, contributes to the complex pressure field, and hence, to the total energy received at a point. The total received energy for a receive cell is calculated by summing the modeled eigenrays, which is illustrated in figure 16.

Propagation analyses differed between at-sea scenarios and those occurring in geographically restricted areas, such as channels and ports. At-sea propagation analyses typically used a series of 18 uniformly spaced radials from each source. Ranges from the source were calculated in 50-m increments, whereas depths were calculated in 25-m increments. A 20 log(r) transmission loss was calculated in the post-processor to supplement the CASS/GRAB output at horizontal ranges less than 50 m and depths within 200 m of the source. For scenarios occurring pierside or within confined channels, radials were adapted to provide the necessary resolution in these unique environments; the depth and range resolution were modified depending on the specific parameters associated with a particular event.

CASS generates a table of depth range points with an associated receive level per location and per source. The CASS tables are manipulated into a binary 3-D structure of range, depth, bearing (e.g., radial angle), and received level.

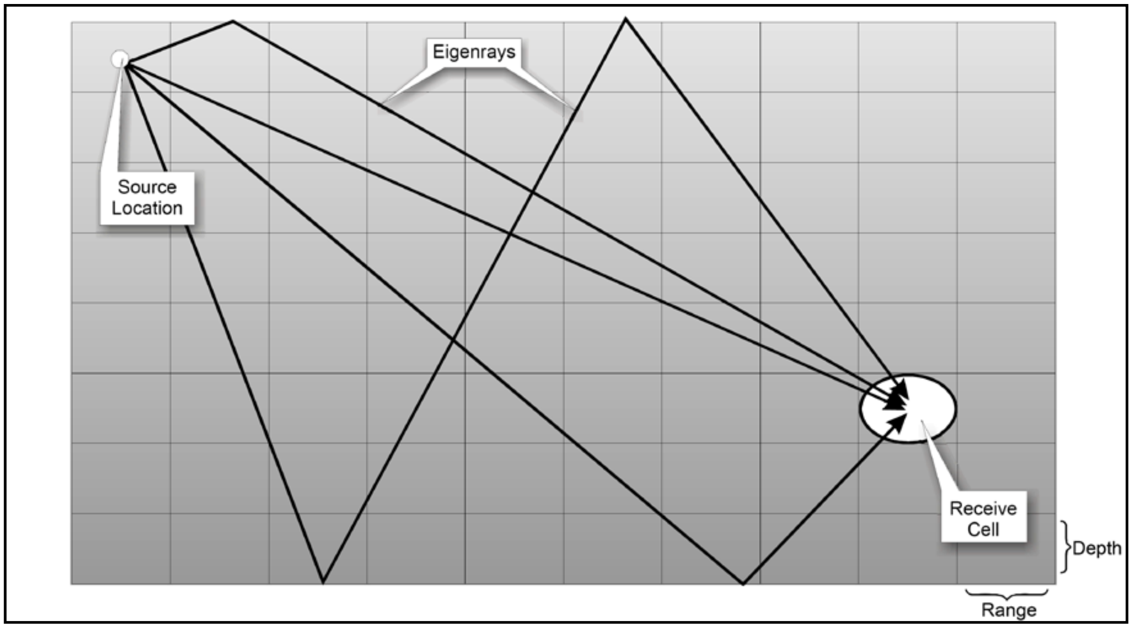

Figure 16. Typical Eigenray Paths for Relatively Short-Range Propagation

6.4.2.2 Acoustic Builder Features for Non-Impulsive Sources. The following features were incorporated into each of the non-impulsive source models:

- The propagation input file was only populated with unique acoustic sources for each scenario, where "unique" was defined from the perspective of the propagation model.
- A table of depth range points with an associated receive level was generated per analysis location per unique source consisting of range, depth and bearing, where bearing was the modeled radial angle.
- Acoustic Builder has a tool to calculate the range to the 120-dB threshold level at all analysis locations for all unique sources.
  - If the 120-dB level has not been reached at the extent of the data file, the propagation analysis was rerun out to a greater distance for whichever sources did not reach the threshold.
  - The largest (i.e., worst case) radial for all CASS analysis points was used to determine the range to 120 dB for that source, and the largest radial for all sources (i.e., worst of the worst) was used to determine the simulation area size for mammal distribution.
  - If all the sources reached the 120-dB threshold, the scenario was updated with the respective ranges for each source to avoid tracking and computing exposures on mammals that were below the 120-dB level.

6.5 MARINE SPECIES DISTRIBUTION BUILDER

Marine Species Distribution Builder distributes marine species within the modeling environment. This section provides an overview of the sources used to populate the Navy Marine Species Density Database (NMSDD), identifies the seasonal designation of density data, and describes the 3-D placement of animals in the water column. The process outlined in this section is applicable to both impulsive and non-impulsive sources, with the exception of the overpopulation factor, where the different methodologies for these two source types are described in section 6.5.4.

6.5.1 Terminology

In the context of this report, animal or marine species is used in a collective sense to refer to both marine mammals (orders Cetacea, Carnivora, and Sirenia) and sea turtles (superfamilies Chelonioidea and Dermochelyidae) because the Phase II modeling applies to all members of both of these designations. An animat functions as a dosimeter, recording energy received from all sources that were active during a scenario.

6.5.2 Sources of Density Data

Marine species density estimation requires a significant amount of effort to collect and analyze survey data to produce a usable estimate. NMFS is the primary agency responsible for estimating marine mammal and sea turtle density within the U.S. Economic Exclusion Zone. Other independent researchers often publish density data for key species in specific areas of interest. The amount of effort required to estimate density for the U.S. Navy's areas of responsibility is beyond the scope of any single organization or beyond any feasible means for the Navy to collect the amount of data required to support. Therefore, the Navy compiled existing, publically available density data for use in NAEMO. The Pacific Navy Marine Species Density Database Technical Reports provide a detailed description of the methods and density data used in NAEMO for the GOA Supplemental EIS/OEIS.

6.5.3 Density Data Compilation and Integration

The density data for input to NAEMO were compiled at Naval Facilities Engineering Command, Pacific. Individual datasets were converted to the Environmental Systems Research Institute, Inc.'s software program ArcGIS. Individual datasets are merged and managed at the Naval Undersea Warfare Center (NUWC) Division, Newport, RI, as part of the global NMSDD.

6.5.4 Distribution of Animals

The distribution of animals in NAEMO encompasses a number of steps that result in the generation of a series of data files containing the time, location, and depth of each animat placed within the modeling area. One data file is created for each modeling area, season, and species of animats distributed. The process starts with the extraction of species density estimates from the NMSDD for a given area and season. The following steps are then taken to distribute the animals within the defined modeling space.

1. An overpopulation factor is determined for the animals within both an inner box associated with the track boundary for the activity and an outer box associated with the farthest possible extent for behavioral disturbance.

2. Literature-derived group size means and standard deviations are used to distribute odontocetes into species-typical groups. All other species are assigned a group size of 1.

3. The groups and their associated animals are then placed onto the exercise area using the density grid as an estimate of the probability of animals occurring in the individual grid cells.

4. Individuals are distributed in the water column using literature-derived depth distributions. New depth assignments are designated for each individual at 4-minute time intervals during the simulation. These changing 3-D distributions with time are then used in the simulation process.

6.5.4.1 Overpopulation. The analysis process used by NAEMO involves a statistical analysis that requires multiple iterations of both platform movement and distributions of animals. Iterations on platform placement and movement are accounted for using multiple simulations of the same event. For each simulation, platforms are assigned a random starting position and course within the inner box. All platform iteration simulations use the same animat distribution files.

Multiple animat distributions are accounted for using an overpopulation factor. To maximize efficiency during the modeling process, overpopulation factors are calculated to limit the number of platform iterations while maintaining a desired coefficient of variation (CV) of raw effects of 0.25. The CV value was chosen by examining CV values of density data that contribute to NMSDD. Typically, the number of platform iterations used for events involving one or more moving platforms is fifteen; fifty iterations are used for events defined with only stationary platforms.

The overpopulation factor is computed based on an equation for distance sampling and includes distance covered by the platform, desired coefficient of variance, distance to TTS and behavioral thresholds, and a scaling factor for uneven distribution of animats. The overpopulation factor is applied to the population of animats computed from the density data within the modeling area and serves as a way to increase the number of distributions of animats included in each simulation. Overpopulation does not affect the distribution process outlined below.

Modeled population discussed in the distribution process below refers to the population computed from the density data with the overpopulation factor applied. The population computed from only the density data is referred to as true population. The estimated effects computed by NAEMO are based on the true population numbers determined from the density data.

Equation (7) is used to calculate the overpopulation factor, based on distance sampling theory where range to the effect criteria is substituted for the visual detection function (Center for Research into Ecological and Environmental Modeling, 2009).

$$OPF = \frac{L}{L_o} = \frac{q}{n_o \left(CV_t\right)^2}, \tag{7}$$

where, L is the estimated total source path length to obtain desired CV, L_o is the distance the source travels within the criteria effect area for one scenario, CV_t is the desired CV of exposed number of animals, n_o is the estimated number of animals in the criteria effect area for one scenario, and q is the scaling factor for uneven distribution of animals over exercise region, or "patchiness." When the actual factor was unknown, a q of 3 was assumed for all simulations (Burnham et al., 1980).

Two overpopulation factors were calculated. The first overpopulation factor is calculated to cover all animats expected in the region from the source out to the greatest distance at which TTS could occur (inner box). The second overpopulation factor is calculated to cover all animats beyond the inner box out to the greatest distance at which behavioral disturbance could occur (outer box). Two different overpopulation factors were generated to reduce computer memory requirements and computational time while still maintaining the desired statistical accuracy. The overpopulation factor for the inner box is generally much higher than for the outer box, since the range to TTS is much smaller than the range to behavioral disturbance; for most species a sufficient number of individuals are expected in the range to produce a statistically accurate estimate of effects. The range to TTS for the inner box is much shorter. Therefore, fewer animals are expected to be exposed within that region. A higher overpopulation factor is required to ensure a large enough sample size of animals to estimate effects. If the higher inner box overpopulation factor were extended to cover the entire modeling area, many more samples within the bootstrapping process would be calculated that would not affect the final average number of effects (i.e., the final mean would be similar with or without the additional samples).

6.5.4.2 Overlay of Modeling Area onto Density Grid. Every event defined in NAEMO has an associated modeling area. The modeling area includes the inner box used to constrain movement of the platforms and a surrounding buffer region called the outer box. The buffer region is defined by the largest sound propagation radial distance from all of the sources being modeled in the event. The black oval line in figure 17 represents the modeling area and the red rectangle represents the inner box. The color contour represents bathymetry data and the cream color represents land.

The modeling area is overlaid onto the density grid obtained from the NMSDD to identify all grids that lie within the modeling area or touch the modeling area boundary. The grid cells shown in figure 17 represent the resolution of density data available for this particular species during a specified season.

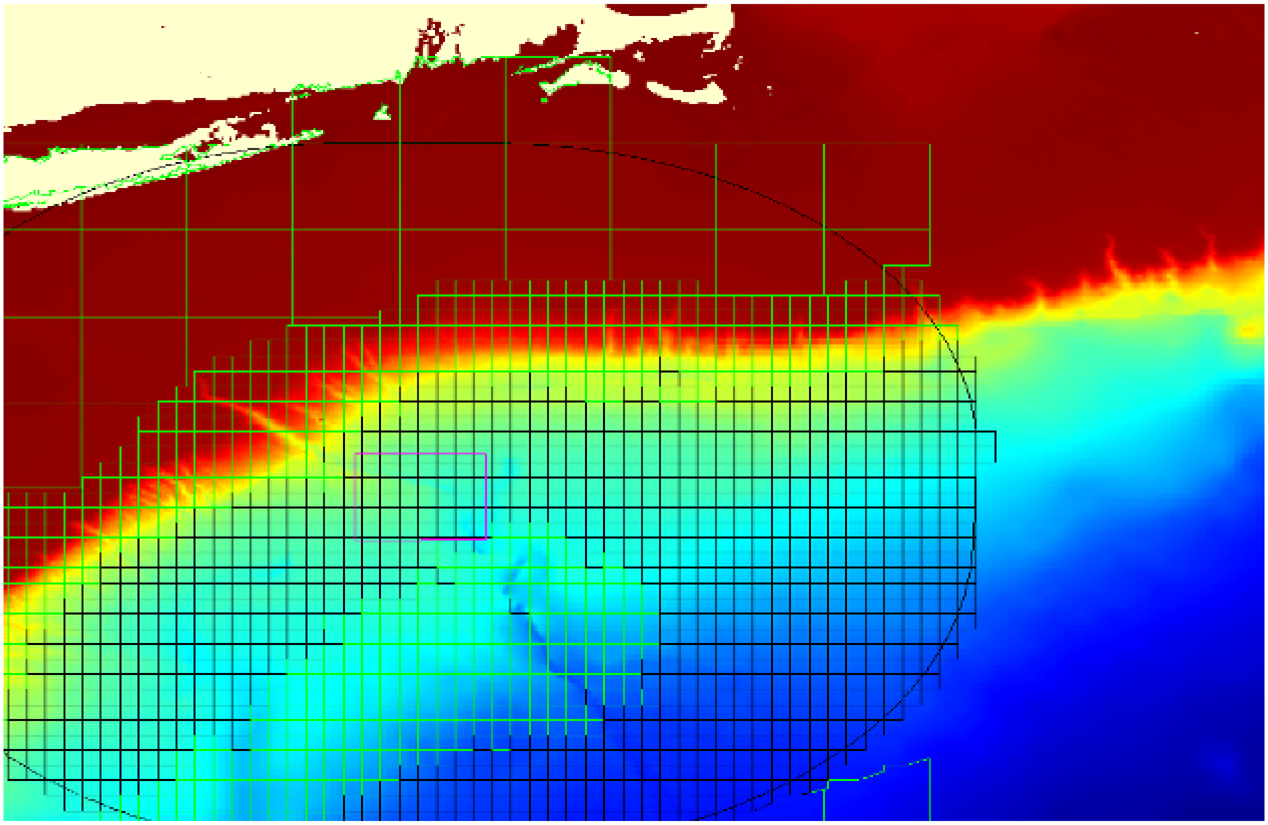

Figure 17. Example Modeling Area With Marine Species Density Grid

6.5.4.3 Computation of the Total Population in the Modeling Area. Using the area of each density grid cell and the density for that grid, the true population of animals present within each grid cell can be computed. Summing all of the population numbers from each grid cell obtains the total true population for the area. If the total true population is less than 0.05 animals, the total true population is set to zero. If the total true population is equal to or greater than 0.05 but less than 1.0, the total true population is rounded up to 1. If the total true population is equal to or greater than 1.0, the total true population is rounded to the nearest whole number.

This process is applied to both the inner box area and the outer box area to produce two population numbers. Inner and outer box overpopulation factors are then applied to the rounded total true population number to compute the inner and outer box total modeled population values. Overpopulation factors are always rounded up to the nearest whole number so the total model populations remain a whole number of animals.

6.5.4.4 Placing Animats into Groups. Each species is distributed independently based on the density distribution of that species across the modeling area. Initially, the species density is extracted from the NMSDD. The number of groups and the number of individuals within each group are then computed. All odontocetes are first clustered into realistically sized groups before being placed within the modeling area. For all other species, group size is set at 1. Information on species-typical group size parameters (mean and standard deviation) was obtained primarily from NMFS cruise reports and published peer-reviewed literature. Group size estimates for the GOA TMAA are provided in Watwood and Buonantony (2012).

For those areas where a species is known to occur, but for which no group size estimates were identified in the published literature, a proxy location was chosen to provide an estimate of group size for that area. Selecting a proxy location is preferable to assigning a group size of one to a species in a particular region, when published data from one or more regions suggest that the species occurs in groups, rather than individually.

To place animats into groups, the probability distribution function for the group size distribution is based on the supplied group size statistics. An inverse Gaussian function is used as the underlying distribution because it has an extended tail that captures the larger upper ranges in group size compared to the mean. The inverse Gaussian has a domain and a shape parameter determined by the mean and standard deviation. A cumulative distribution function is then generated from the probability distribution function. Numbers between 0 and 1 are randomly drawn to interrogate the cumulative distribution function and determine a group size. This process continues until all animals expected within the simulation area have been assigned to groups.

6.5.4.5 Placing Animats Within the Modeling Area. The same process is used for assigning groups of animals to density grid cells as was described above to assign individuals to groups. The density values of cells within the simulation area are normalized to the sum of the density values across the simulation area. The normalized, non-zero values are vectorised and used as a probability distribution function for animal presence in the grid cells, which is then converted to a cumulative distribution function. Random numbers are drawn to interrogate the inverse cumulative distribution function and determine in which grid cell each group should be placed.

Individual group members are then randomly distributed into each assigned grid cell. This is due to a lack of information on inter-animal distance and group spread for most marine species. During model development, an initial nominal simulation was run to determine the effect of group spread distance (radius of the circle within which animats would be randomly placed) on Marine Mammal Protection Act criteria effect values. Table 10 gives the values associated with the various distances for group spread. Generally, the number of behavioral effects increased with increasing group spread values. As most distributions for NAEMO place animats in grid cells of NODES size or larger (> 4,300 m), this distribution technique is considered conservative compared to grouping animats more tightly. Figure 18 shows an example distribution using the NUWC-developed Marine Species Distribution Builder in NAEMO.

6.5.4.6 Placing Animats at Depth. Animals are distributed in depth based on species-typical depth distribution data. For species with sufficient data, region-specific profiles were created. Otherwise, a single depth distribution profile was created for all areas. Specific data used to generate the depth distribution profiles are included in Watwood and Buonantony (2012).

Similar to placing groups of animats in density grid squares, individual animats are placed in depth by interrogating the cumulative distribution function generated from their species-specific depth distribution profile. A random number is drawn, and the cumulative distribution function is interrogated, for each animat to be placed at depth. This process is repeated for every 4 minutes of the simulation time, which means that an animat's depth changes every 4 minutes. For static animats, this process recreates the vertical movement of animals throughout the water column over time. The end result of the mammal distribution process is a series of data files (one for each species and season) that contains a time history of each animal's position and depth.

Figures 19 and 20 show the effect values and CV values for a nominal scenario where the effect of update rate is tested for a few shallow- and deep-diving cetaceans. The update rate ranges from every second to once during the 120-minute scenario. The effect and CV values are then compared to the values using a fully 3-D moving distribution, created with the Marine Mammal Movement and Behavior Software (Houser, 2006). The 4-minute update interval was chosen through visual inspection of figure 19 which shows the effect values at 4-minute updates to be comparable to the effect values using the 3-D moving distribution. Effect values generally begin to decline when the update interval is more than 5 minutes. Updating animat depth at 4-minute intervals saves computational time over more frequent updates without impacting effect values.

Table 10. Effect of Varying Group Dispersion Distances on Behavioral Risk Function (BRF), TTS, and PTS Values for Nominal Simulation

Species	Group Size		250 m			500 m			1,000 m			4,300 m (NODES)			5,000 m			25,000 m		
	Mean	**Std Dev**	**BRF**	**TTS**	**PTS**	**BRF**	**TTS**	**PTS**	**BRF**	**TTS**	**PTS**	**BRF**	**TTS**	**PTS**	**BRF**	**TTS**	**PTS**	**BRF**	**TTS**	**PTS**
Common Dolphin	27.9	29.1	23	2	0	24	2	0	25	1	0	26	2	0	28	2	0	27	2	0
Pygmy Killer Whale	9.2	5.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Risso's Dolphin	8.5	1.1	3	0	0	3	0	0	3	0	0	3	0	0	4	0	0	3	0	0
Short-Finned Pilot Whale	15.4	4.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Long-Finned Pilot Whale	10.2	1.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern Bottlenose Whale	3.3	1.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kogia spp.	1.5	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Atlantic White-Sided Dolphin	15.9	17.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fraser's Dolphin	136.6	58.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sowerby's Beaked Whale	3.7	1.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blainville's Beaked Whale	3.3	1.1	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Gervais' Beaked Whale	3	0.1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
True's Beaked Whale	1.8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Killer Whale	2.5	0.7	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Melon-Headed Whale	23.3	33.9	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Pilot Whale	15.4	4.8	11	0	0	11	0	0	12	0	0	12	1	0	12	1	0	12	1	0
Sperm Whale	4.5	5.3	5	1	1	5	1	1	4	1	1	4	1	1	4	1	1	4	1	1
Harbor Porpoise	2.5	1.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pantropical Spotted Dolphin	24.6	23.4	2	0	0	2	0	0	2	0	0	2	0	0	1	0	0	2	0	0
Rough Toothed Dolphin	5.5	3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Clymene Dolphin	80	75.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Striped Dolphin	45.6	37.5	16	1	0	16	1	0	16	1	0	17	1	0	18	1	0	24	1	0
Atlantic Spotted Dolphin	28.4	10.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spinner Dolphin	27.6	25.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottlenose Dolphin	14.2	7.6	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Cuvier's Beaked Whale	2.8	0.6	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
			65	**4**	**1**	**66**	**4**	**1**	**67**	**3**	**1**	**69**	**5**	**1**	**71**	**5**	**1**	**78**	**5**	**1**

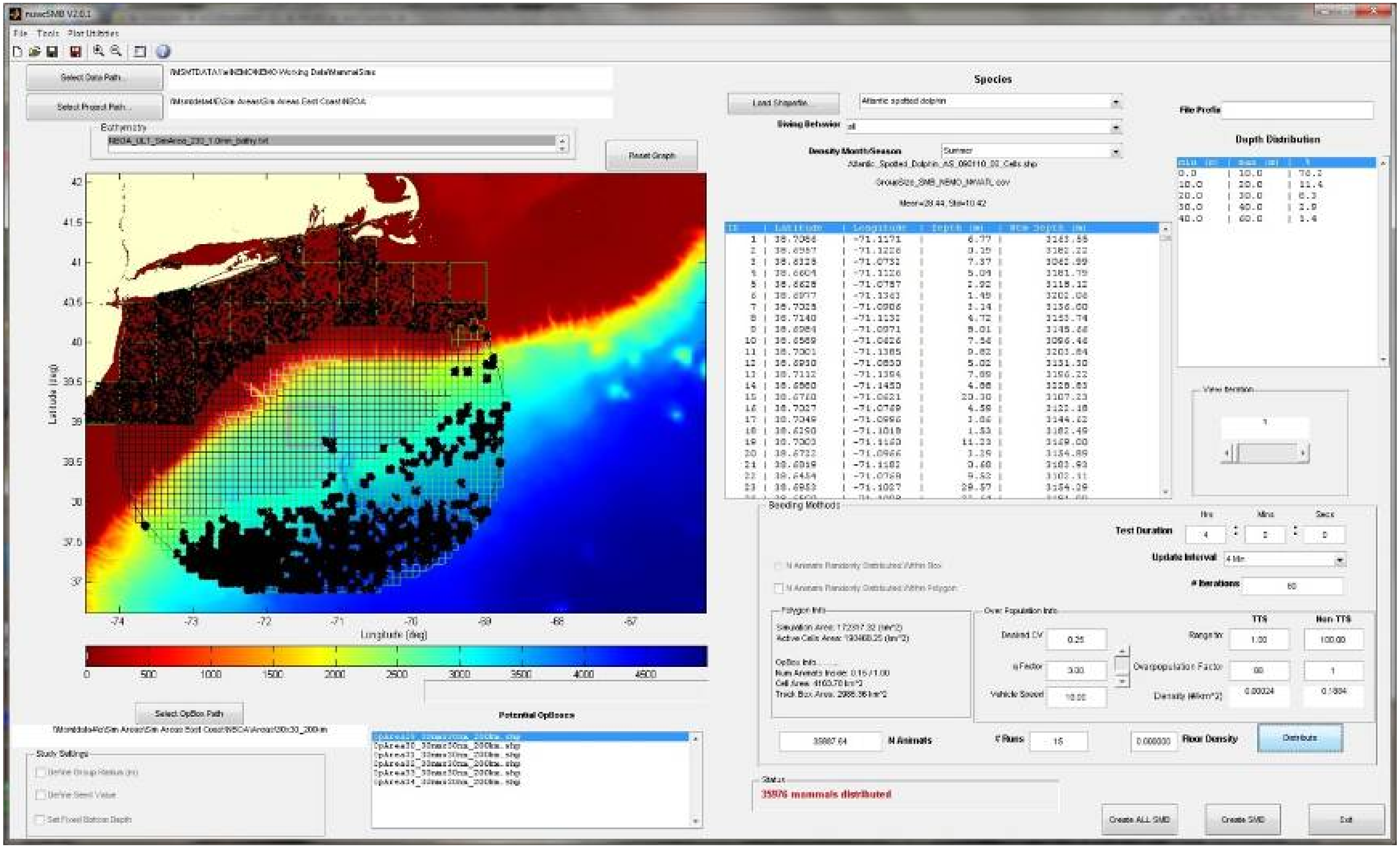

Figure 18. Example Distribution for Atlantic Spotted Dolphin in the Narragansett Bay Operating Area During the Summer Season (Black dots represent individual animats.)

6.5.4.7 Marine Species Placement Assumptions. There are limitations to the data used in NAEMO, and the results must be interpreted with consideration for these known limitations. Output from the NAEMO relies heavily on the quality of both the input parameters and impact thresholds and criteria. When there was a lack of definitive data to support an aspect of the modeling (such as lack of well-described diving behavior for all marine species), conservative assumptions believed to overestimate the number of effects were chosen:

- Animats are modeled as being underwater and facing the source. Therefore, they are always predicted to receive the maximum sound level at their position within the water column (e.g., the model does not account for conditions such as body shading, porpoising out of the water, or an animal raising its head above water).
- Animats do not move horizontally (but change their position vertically within the water column), which may overestimate physiological effects such as hearing loss, especially for slow-moving or stationary sound sources in the model.
- Animats are stationary horizontally and do not avoid the sound source, unlike in the wild where animals would most often avoid exposures at higher sound levels, especially those exposures that may result in permanent hearing loss (PTS).

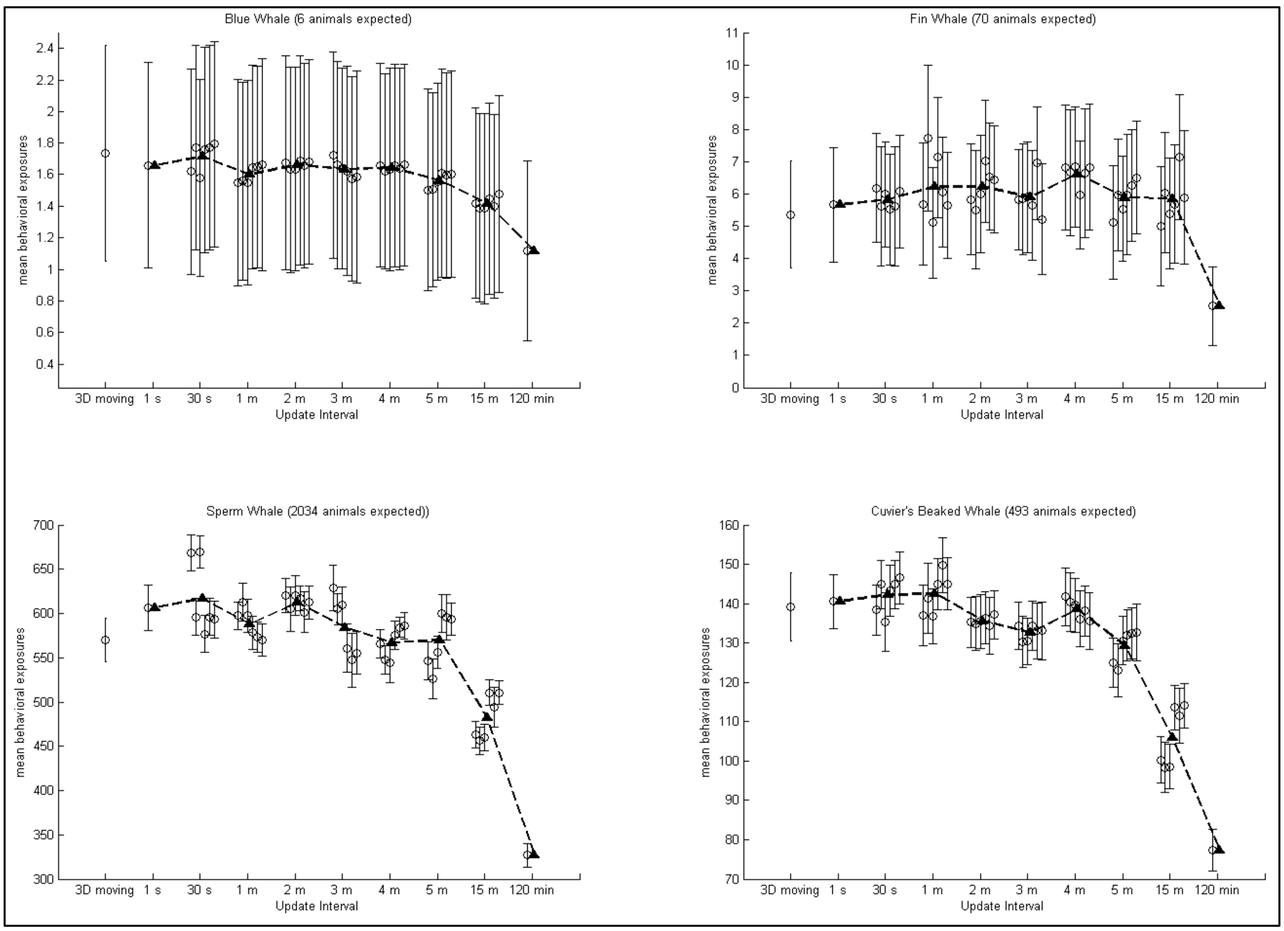

Figure 19. Effect of Update Rate on Estimated Values for Two Shallow-Diving Cetaceans (Top Row) and Two Deep-Diving Cetaceans (Bottom Row)
(Error bars represent ± 1 standard deviation. The thick dotted line indicates the mean value for all simulations at each update interval.)

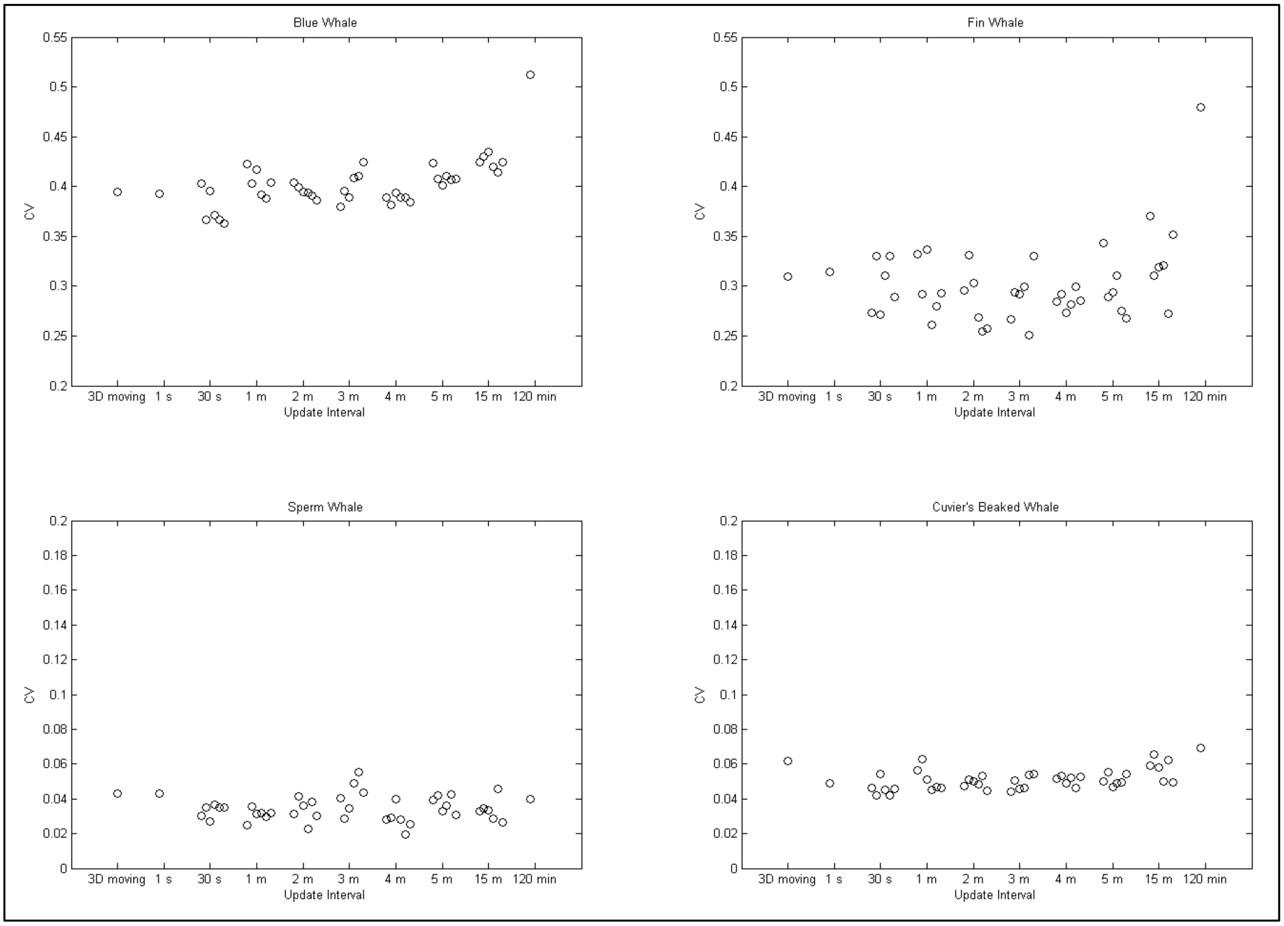

Figure 20. Effect of Update Rate on CV Values for Two Shallow-Diving Cetaceans (Top Row) and Two Deep-0 Diving Cetaceans (Bottom Row)

7. NAEMO SIMULATION PROCESS

The NAEMO simulation process is the step where all of the previously defined data come together and are used to estimate the acoustic effects on the marine species. The scenario simulation process is defined by three modules within the NAEMO software. The first module, Scenario Simulator, combines scenario definition from Scenario Builder, data created in Acoustic Builder, and animat distributions created in Marine Species Distribution Builder to produce a data file containing the sounds received by each animat. The second module, Post Processor, reads the animat data files created by Scenario Simulator, applies the frequency-based weighting functions, and conducts a statistical analysis to estimate effects associated with each marine species group based on the specified criteria thresholds. Results from each analysis are stored in a species exposure data file. The third and final module, Report Generator, provides a mechanism to assemble all of the individual species exposure data files created by Post Processor and compute annual effect estimates. Estimated annual effects can be grouped by activity, season, and geographic region before outputting the results to comma-separated text files that can be used for further examination of the data. The following sections provide an overview of each module.

7.1 SCENARIO SIMULATOR

The purpose of Scenario Simulator is to execute the simulation from the scenario definition file and determine the level of sound received by each animat. To do this, Scenario Simulator interprets the data stored in the scenario definition file to determine the starting location, direction, and depth of each platform. Scenario Simulator then steps through time and interrogates each of the platform sources to determine which sources are actively emitting sound during that time step.

The simulation begins with a time equal to zero and progresses incrementally along in 1-second increments until the end of the scenario. For each time step, the process begins with first computing the beam pattern area and direction of sound source emission for each active source. The beam pattern area is computed from the horizontal beam pattern and maximum propagation distance, which is stored in the Scenario definition file. For example, the area for a source with a ninety-degree horizontal beam pattern and a maximum propagation distance of 100 kilometers would equate to a quarter of a circle whose radius is 100 kilometers. The beam pattern direction is based on the direction of travel of the platform and any offsets defined for the horizontal beam pattern. The next step in the process identifies all animats that fall within each defined beam pattern area.

Impulsive and non-impulsive propagation data are computed at multiple locations within each modeling box to account for platforms moving during the simulation. The exception to this is scenarios that involve only stationary platforms. At each time step, the position of each platform is compared to the locations of each propagation analysis point to determine the closest propagation file.

For each animat identified in the animat beam pattern list, a lookup in the sound source propagation file is performed to determine the received sound level for that animat. The lookup is conducted based on the bearing and distance from the platform to the animat and the depth of the animat. The closest matching point within the propagation file is used.

Data for each animat are stored in a Scenario Simulator data file. Data stored in the file include simulation time, platform name, source name, source mode name, source mode frequency, source mode level, ping length, platform location (latitude/longitude), platform depth, species name, animal identification number, animal location (latitude/longitude), animal depth, animal distance from source, and sound receive levels. A single animat may have one or more entries in the data file at each time step depending on the number of sources determined to be within hearing distance.

Sound sources with active times less than 1 second are evaluated within the current 1-second time step. For example, if a source is active for one tenth of a second and repeats this every one-half of a second, then both active times (t = 0 second and t = 0.5 second) that fall within the current time step are processed within the same time step. The next active time of t =1.0 second would be processed in the next time step along with the t =1.5 seconds.

7.2 POST PROCESSOR

Post Processor (figure 21) utilizes each of the data files from all track iterations created by Scenario Simulator to conduct a statistical analysis of the animat data to compute estimated effects associated with each marine species group. The number of track iteration files is typically 50 for impulsive scenarios and 15 for all non-impulsive scenarios involving moving platforms.

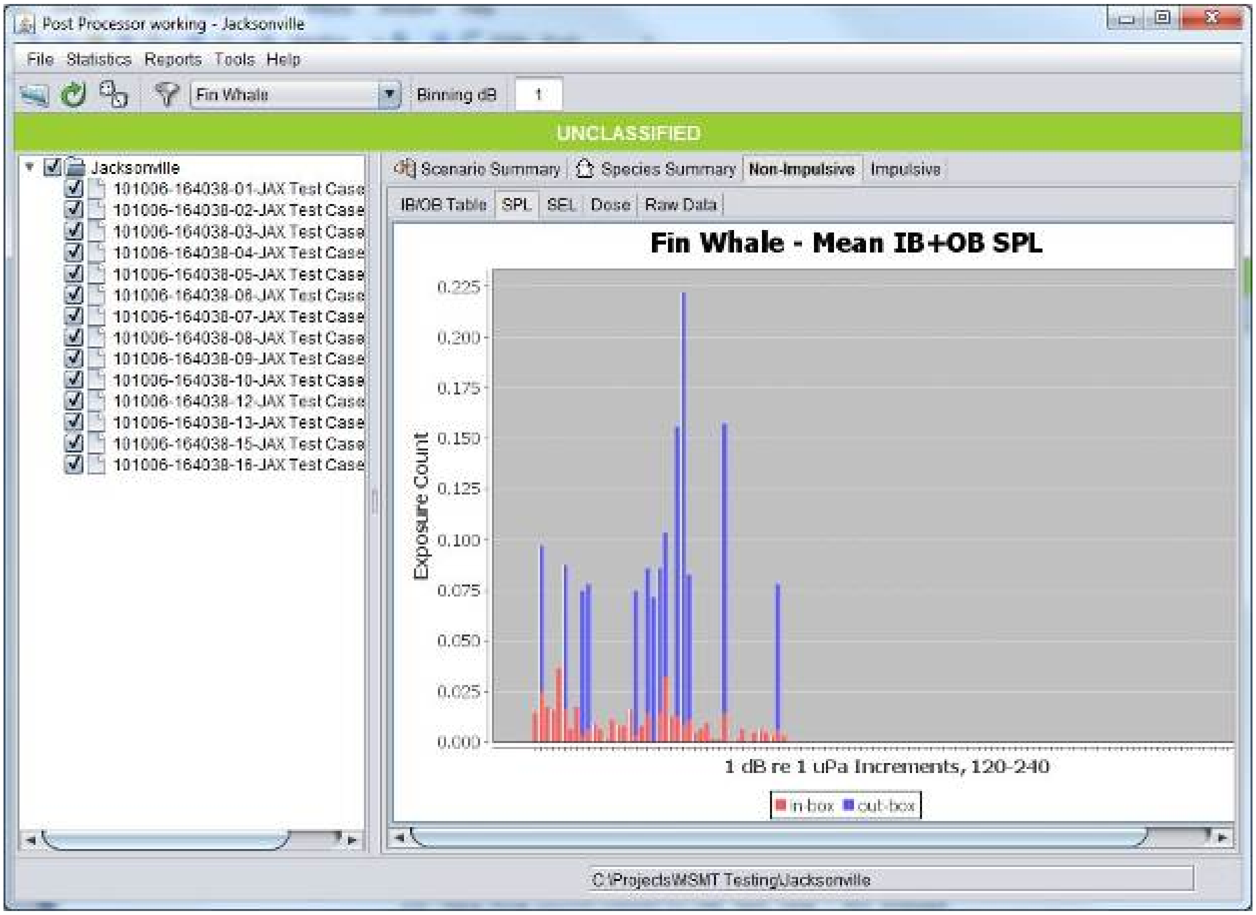

Figure 21. Example Post Processor Screen

7.2.1 Impulsive Sources

Post Processor first applies the appropriate frequency-based, M-Weighting curves defined by the marine species criteria to adjust the 1/3-octave received levels. Maximum received SPL and accumulated SEL over the entire duration of the event are computed for each animat based on the weighted received sound levels. Accumulated SEL represents the accumulation of energy from all 1/3-octave quantities and from multiple source exposures. The Post Processor applies the injury criteria to each animat to determine if they exceed either threshold.

Data are then processed using a bootstrapping routine to compute the number of animats exposed to SPL and SEL in 1-dB bins across all track iterations and population draws. SEL levels are checked during this process to ensure that all animats are grouped in only one criteria category. Additional detail on the bootstrapping process is included in section 7.2.3.

A mean number of SPL and SEL exposures are computed for each 1-dB bin. The mean value is based on the number of animats exposed at that dB level from each track iteration and population draw.

The number of animat effects to each criterion is determined from the cumulative number of animats exceeding each threshold. Each animat can only be reported under a single criterion (e.g., once an animat is reported for mortality, it would not additionally be reported under TTS). Behavioral effects are only computed for animats that experience two or more pulses.

7.2.2 Non-Impulsive Sources

Post Processor first applies the appropriate frequency-based M-weighting curves to adjust the received sound levels. During this process, the horizontal range between the animat and source is checked to see if it is less than or equal to 50 m (the first range point) and the difference in depth of the source and the animat is checked to see if it is less than or equal to 200 m. If the horizontal range is less than 50 m or the vertical range is less than 200 m, the receive level read from the data file is discarded and the receive level is recomputed using equation (8):

$$\text{Received Level} = \text{Source Level} - 20\log_{10}(\text{slant range}). \tag{8}$$

Slant range is computed using the range from the source to the animat and the difference in depth between the source and animat.

Maximum received SPL and accumulated SEL over the entire duration of the event are computed for each animat based on the weighted received sound levels. These data are then processed using a bootstrapping routine to compute the number of animats exposed to SPL and SEL in 1-dB bins across all track iterations and population draws. SEL is checked during this process to ensure that all animats are grouped in either an SPL or SEL category. Additional detail on the bootstrapping process is included in section 7.2.3.

A mean number of SPL and SEL simulated exposures are computed for each 1-dB bin. The mean value is based on the number of animats exposed at that dB level from each track iteration and population draw. The BRF curve is applied to each 1-dB bin to compute the number of behaviorally exposed animats per bin. The number of behaviorally affected animats per bin is summed to produce the total number of behavior effects.

Mean 1-dB bin SEL exposures are then summed to determine the number of PTS and TTS effects. PTS values represent the cumulative number of animats affected at or above the PTS threshold. TTS values represent the cumulative number of animats exposed at or above the TTS threshold and below the PTS threshold. Animats exposed below the TTS threshold were grouped in the SPL category.

7.2.3 Bootstrap Approach

Estimation of effects in NAEMO is accomplished through the use of a simple random sampling with replacement by way of statistical bootstrapping. This sampling approach was chosen because the number of individuals of a species expected within an area over which a given Navy activity occurs is often too small to offer a statistically significant sampling of the geographical area. Additionally, NAEMO depends on the fact that individual animats move vertically in the water column at a specified displacement frequency for sufficient sampling of the depth dimension. By overpopulating at the time of animat distribution and drawing samples from this overpopulation with replacement, NAEMO is able to provide sufficient sampling in the horizontal dimensions for statistical confidence. Sampling with replacement also produces statistically independent samples, which allows for the calculation of metrics such as standard error and confidence intervals for the underlying Monte Carlo process.

For each scenario and each species, the number of samples equating to the overpopulation factor is drawn from the raw data. Each sample size consists of the true population size of the species evaluated. Within each sample size drawn, each animat is evaluated to determine if the received SEL is above or below the threshold for that species. If above the SEL threshold, the animat is stored in the SEL bin table by level of SEL. If not, the animat is stored in the SPL bin table by level of maximum received SPL. This process is repeated for each overpopulation draw and ship track iteration. The end result are two tables of data that contain N number of rows; where N = overpopulation x ship iterations. One table contains all of the animats exposed to SEL grouped by level of SEL and the other contains all animats exposed to SPL grouped by level of SPL.

For example, assume that an overpopulation factor of 10 was defined for a given species and that 15 ship track iterations were completed. The bootstrap Monte Carlo process would have generated statistics for 10 draws on each of the 15 raw animat data files generated by the 15 ship tracks evaluated for this scenario, thereby yielding 150 independent sets of effect estimates. Samples drawn from the overpopulated population are replaced for the next draw, allowing for the re-sampling of animals. The resultant 150 sets of effects were then combined to yield a mean number of effects and a 95% confidence interval per species for the scenario. In addition to the mean, the statistics included the upper and lower bounds of all samples.

The SEL tables are then processed to compute the mean number of animats in each 1 dB bin based on all rows in the SEL table. The total number of animats exposed to TTS is then determined by summing the mean number of animats in each 1 dB bin up to an including the TTS threshold. The total number of animats exposed to PTS is determined by summing the mean number of animats in each bin above the TTS threshold.

The SPL tables are then processed to compute the mean number of animats in each 1 dB bin based on all rows in the SPL table. The behavioral risk function curve is applied to the mean SPL table to compute the mean number of behavioral effects. The number of behavioral effects is computed by first multiplying the number of animats in each 1 dB bin times the probability of behavioral effect for that bin and then summing each of the resultant quantities. The probability is determined from the risk function curve using the bin dB level.

Figure 22 depicts the bootstrapping approach used to calculate simulation statistics. This figure represents a hypothetical scenario with a humpback whale population size of three individuals, an overpopulation factor of three, and three ship track iterations. The symbols μ_{ij} and σ_{ij} represent the mean and variance, respectively, of the number of effects for population draw j of ship iteration i. The symbols $\overline{x_i}$ and $\overline{\sigma_i}$ represent the mean and variance, respectively, of the number of effects for ship iteration i. These numbers were arrived at by calculating the mean and variance of the means from each population draw for a given ship iteration. Finally, $\overline{X}$ and $\overline{S}$ represent the mean and variance, respectively, of the number of effects for the entire simulation. These numbers were arrived at by calculating the mean and variance of the mean number of effects from each ship iteration.

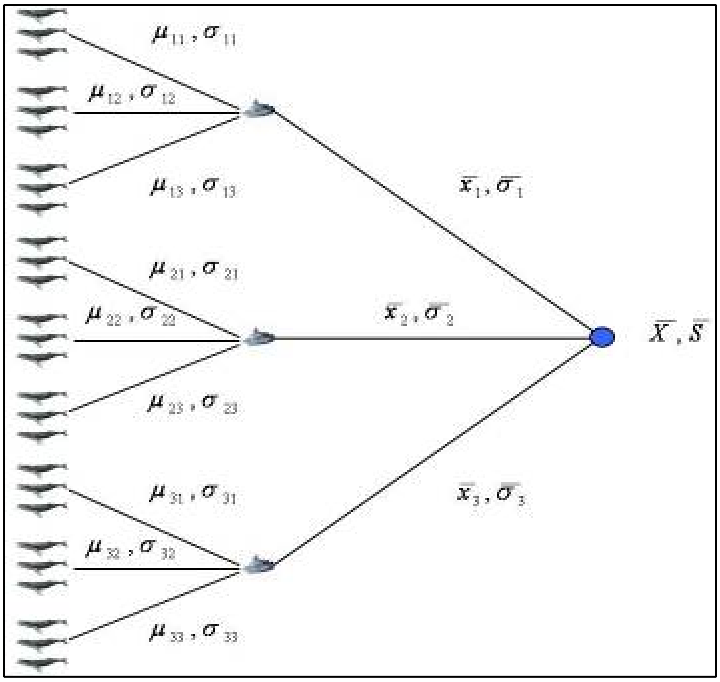

Figure 22. Bootstrapping Approach Used to Calculate Simulation Statistics

7.3 REPORT GENERATOR

Report Generator (figure 23) provides a mechanism to assemble all of the individual species exposure data files created by Post Processor and compute annual effect estimates. Estimated annual effects can be grouped by activity, season, and geographic region before outputting the results to comma separated text files that can be used for further examination of the data.

All scenarios analyzed in NAEMO were evaluated as single events occurring within a given season and location. Scenarios that occurred over multiple seasons and locations were modeled for each combination of season and location. The annual estimated effects for a single scenario are determined by taking the average of all seasons and locations modeled for that scenario. To create the average effects, each scenario was multiplied by a factor based on the number of seasons, locations, and events per season that scenario would be conducted. Each factored scenario effect is then summed together to produce the average scenario effect. Total annual effects resulting from all scenarios modeled are then the summation of each scenario's averaged effect.

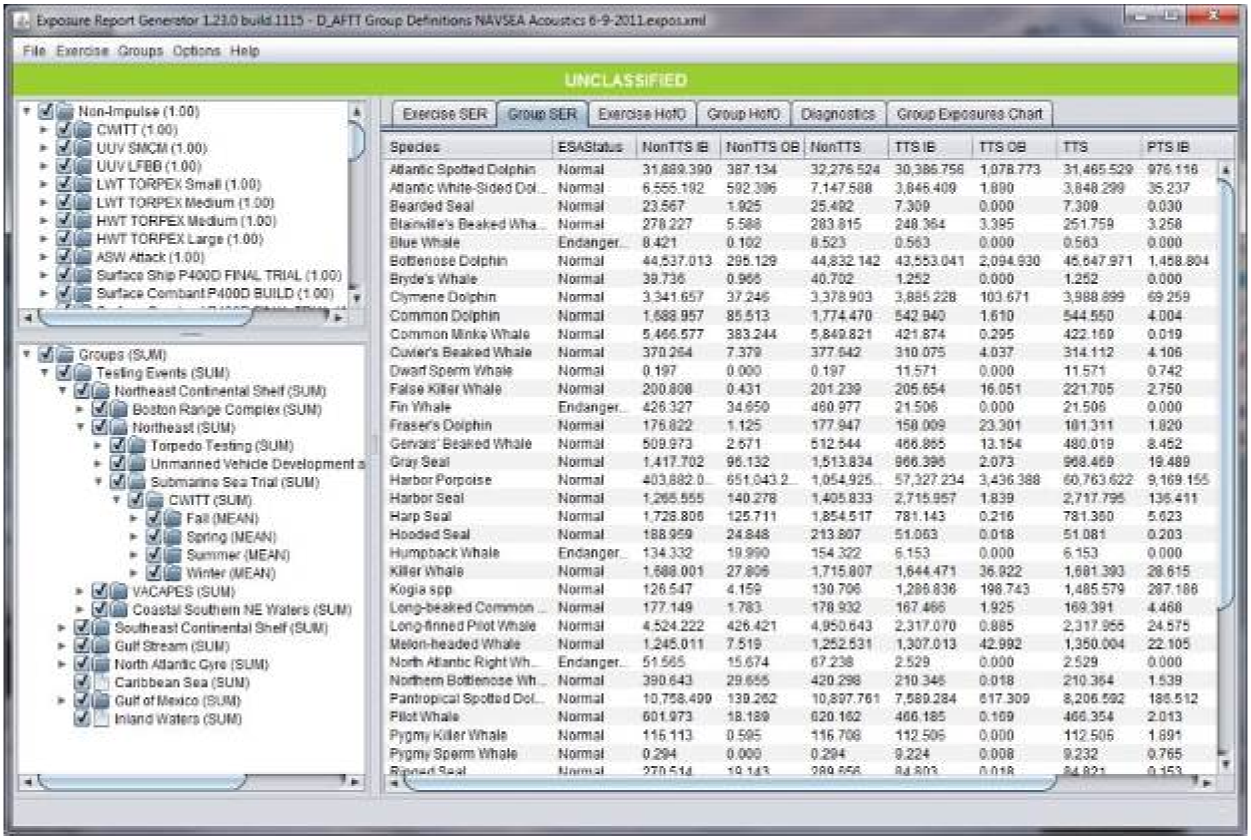

Figure 23. Example Report Generator Screen

7.4 POST-MODELING ANALYSIS PROCESS

The model estimated effects are further analyzed to consider factors not currently implemented in NAEMO. This additional analysis considers (1) the avoidance by certain species (i.e., harbor porpoise and beaked whales) to human presence prior to the start of activity, (2) the avoidance of marine species to high level exposures from a sound source resulting in potential injury, and (3) the implementation of mitigation measures that would halt or delay an activity if marine species are within the mitigation zone of the sound source. Details on the methodology used to estimate the total potential effects are provided in the GOA Supplemental EIS/OEIS and the Post-Model Quantitative Analysis of Animal Avoidance Behavior and Mitigation Effectiveness Technical Report for Gulf of Alaska Training Activities.

8. GOA ESTIMATED EFFECTS

8.1 HOURS OF OPERATION

NAEMO provides the number of hours of non-impulsive source usage and the number of counts of impulsive sources used annually for training activities. Exposure Report Generator reads the simulation files to calculate the total hours of each non-impulsive source mode's active time or the number of occurrences of each mode for impulsive sources. A multiplier is applied to normalize the results from each modeling box, number of days each event would occur, and the number of events that would occur in a season. The annual totals are the summation of the seasonal values. The annual counts of each impulsive source (table 11), as well as the counts and hours for non-impulsive sources (table 12) are provided below.

Table 11. Annual Usage of Impulsive Sources Modeled forTraining Activities

Source Class Category	Training Activities		
	No Action Alternative	Alternative 1	Alternative 2
E4	0	40	80
E5	34	56	112
E6	0	1	2
E7	0	2	4
E8	0	3	6
E9	42	71	142
E10	4	16	32
E11	0	1	2
E12	2	2	4

Table 12. Annual Usage of Non-Impulsive Sources Modeled for Training Activities

Source Class Category	Unit	Training Activities		
		No Action Alternative	Alternative 1	Alternative 2
ASW2	Count	0	40	80
ASW3	Hours	0	273	546
ASW4	Count	0	6	12
HF1	Hours	0	12	24
HF6	Hours	0	40	80
MF1	Hours	0	271	541
MF3	Hours	0	24	48
MF4	Hours	0	26	53
MF5	Count	0	126	252
MF6	Count	0	11	21
MF11	Hours	0	39	72
TORP2	Count	0	1	2

8.2 MODELED EFFECTS

Tables 13 and 14 provide the modeled effects for annual training events using non-impulsive sources and impulsive sources, respectfully.

Table 13. Modeled Effects for Annual Training Events (Non-Impulsive Sources)

Species	No Action Alternative			Alternative 1			Alternative 2		
	Non-TTS	TTS	PTS	Non-TTS	TTS	PTS	Non-TTS	TTS	PTS
Odontocetes									
Baird's Beaked Whale	0.00	0.00	0.00	200.58	0.25	0.00	401.16	0.51	0.00
Cuvier's Beaked Whale	0.00	0.00	0.00	1269.68	2.58	0.00	2539.36	5.15	0.00
Dall's Porpoise	0.00	0.00	0.00	1099.24	6766.17	203.21	2198.47	13532.33	406.42
Harbor Porpoise	0.00	0.00	0.00	3705.60	0.00	0.00	7411.20	0.00	0.00
Killer Whale	0.00	0.00	0.00	364.83	17.00	0.26	729.65	34.00	0.53
Pacific White-Sided Dolphin	0.00	0.00	0.00	939.43	42.73	0.00	1878.85	85.46	0.00
Sperm Whale	0.00	0.00	0.00	98.16	0.51	0.00	196.32	1.03	0.00
Stejneger's Beaked Whale	0.00	0.00	0.00	576.97	0.47	0.00	1153.95	0.94	0.00
Mysticetes									
Blue Whale	0.00	0.00	0.00	38.04	9.38	0.34	76.07	18.77	0.68
Fin Whale	0.00	0.00	0.00	941.10	343.13	7.00	1882.20	686.27	14.01
Gray Whale	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Humpback Whale	0.00	0.00	0.00	54.03	16.46	0.30	108.06	32.93	0.59
Minke Whale	0.00	0.00	0.00	35.19	8.61	0.22	70.37	17.23	0.44
North Pacific Right Whale	0.00	0.00	0.00	2.54	1.01	0.02	5.09	2.02	0.05
Sei Whale	0.00	0.00	0.00	5.33	1.57	0.01	10.66	3.14	0.03
Pinnipeds									
California Sea Lion	0.00	0.00	0.00	2.79	0.00	0.00	5.58	0.00	0.00
Harbor Seal	0.00	0.00	0.00	1.83	0.59	0.04	3.66	1.18	0.08
Northern Elephant Seal	0.00	0.00	0.00	100.63	21.76	0.45	201.26	43.53	0.90
Northern Fur Seal	0.00	0.00	0.00	713.63	0.70	0.00	1427.26	1.41	0.00
Steller Sea Lion	0.00	0.00	0.00	621.86	0.00	0.00	1243.72	0.00	0.00
Totals	**0.00**	**0.00**	**0.00**	**10771.45**	**7232.95**	**211.86**	**21542.90**	**14465.89**	**423.72**

Table 14. Modeled Effects for Annual Training Events (Impulsive Sources)

Species	No Action Alternative						Alternative 1						Alternative 2					
	Non-TTS	TTS	PTS	Slight GI Tract	Slight Lung	Mortality	Non-TTS	TTS	PTS	Slight GI Tract	Slight Lung	Mortality	Non-TTS	TTS	PTS	Slight GI Tract	Slight Lung	Mortality
Odontocetes																		
Baird's Beaked Whale	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Cuvier's Beaked Whale	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00
Dall's Porpoise	22.71	1.20	1.14	0.00	0.37	0.22	47.26	8.15	2.03	0.00	0.65	0.19	94.51	16.30	4.05	0.00	1.31	0.38
Killer Whale	0.02	0.02	0.01	0.00	0.01	0.00	0.02	0.02	0.01	0.00	0.01	0.01	0.04	0.04	0.01	0.00	0.02	0.01
Pacific White-Sided Dolphin	0.02	0.00	0.00	0.00	0.05	0.02	0.01	0.02	0.01	0.00	0.09	0.02	0.02	0.05	0.01	0.00	0.18	0.04
Sperm Whale	0.02	0.02	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.03	0.02	0.00	0.00	0.00	0.00
Stejneger's Beaked Whale	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Blue Whale	0.01	0.02	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.00	0.00	0.04	0.06	0.00	0.00	0.00	0.00
Fin Whale	0.14	0.19	0.04	0.01	0.01	0.00	0.23	0.34	0.06	0.02	0.01	0.00	0.47	0.68	0.12	0.03	0.01	0.00
Humpback Whale	0.02	0.01	0.00	0.00	0.00	0.00	0.03	0.02	0.00	0.00	0.00	0.00	0.06	0.05	0.00	0.00	0.00	0.00
Minke Whale	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.04	0.00	0.00	0.00	0.00
North Pacific Right Whale	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sei Whale	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
California Sea Lion	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Harbor Seal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Northern Elephant Seal	0.03	0.05	0.01	0.00	0.01	0.00	0.05	0.09	0.02	0.00	0.01	0.00	0.10	0.17	0.04	0.00	0.02	0.00
Northern Fur Seal	0.00	0.02	0.00	0.00	0.08	0.03	0.00	0.05	0.01	0.00	0.16	0.06	0.00	0.09	0.01	0.00	0.32	0.11
Steller Sea Lion	0.00	0.01	0.01	0.00	0.02	0.01	0.00	0.03	0.02	0.00	0.03	0.02	0.00	0.06	0.04	0.00	0.05	0.06
Totals	**22.99**	**1.55**	**1.21**	**0.01**	**0.55**	**0.28**	**47.65**	**8.80**	**2.15**	**0.02**	**0.97**	**0.30**	**95.30**	**17.60**	**4.30**	**0.03**	**1.91**	**0.59**

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APPENDIX
SOURCE CLASSES AND MODELED SOURCES

Sources modeled within each source class category are provided in table A-1 for impulsive sources and in table A-2 within each source class for non-explosive impulsive and non-impulsive sources. The sources listed below only include those that were modeled; for example, no sources are currently modeled within the MF7-MF10 bins. Therefore, they are not included in the table below.

Table A-1. Impulsive Sources Modeled Within Each Source Class

Source Class	Examples of Representative Source Name(s)
E4	**Explosive Source**
	Improved Extended Echo Ranging Buoy
E5	**Explosive Source**
	5-in. Projectile
E6	**Explosive Source**
	Hellfire missile
E7	**Explosive Source**
	HARM
E8	**Explosive Source**
	Maverick missile
E9	**Explosive Source**
	500-lb bomb
E10	**Explosive Source**
	Harpoon missile
	Penguin missile
	1,000-lb bomb
E11	**Explosive Source**
	Classified Sources
E12	**Explosive Source**
	2,000-lb bomb

Table A-2. Non-Impulsive Sources Modeled Within Each Source Class

Source Class	Examples of Representative Source Name(s)
MF1	**Hull-Mounted Surface Ship Sonar**
	AN/SQS-53 Series Sonar
	AN/SQS-61 Series Sonar
MF3	**Hull-Mounted Submarine Sonar**
	AN/BQQ-10 Series Sonar
	AN/BQQ-5 Series Sonar
MF4	**Helicopter-Deployed Dipping Sonar**
	AN/AQS-22 – Airborne Low Frequency Sonar
	AN/AQS-13 – Airborne Dipping Sonar
MF5	**Active Acoustic Sonobuoy**
	AN/SSQ-62 – Directional Command Active Sonobuoy System
MF6	**Active Underwater Sound Signal Devices**
	Mk 84 SUS
MF11	**Hull-Mounted Surface Ship Sonar with an Active Duty Cycle Greater Than 80%**
	High Duty Cycle Sonar – (AN/SQS-53C HDC)
HF1	**Hull-Mounted Submarine Sonar**
	AN/BQQ-10 – Submarine HF Sonar
	Submarine Navigation Systems
HF6	**Active Sources from 180 dB up to 200 dB Not Otherwise Binned**
	Portable Underwater Tracking System
ASW2	**MF Multistatic Active Systems**
	Multistatic Active Coherent Sonobuoy
ASW3	**MF Towed Active Acoustic Countermeasure Systems**
	NIXIE
ASW4	**MF Expendable Active Acoustic Device Countermeasure Systems**
	Acoustic Decoy Countermeasure
	Naval Acoustic Electro-Mechanical Beacon
P2	**HF Tracking Pinger**
	Portable Underwater Tracking System
TORP2	**Heavyweight Torpedo**
	Mk 48 – Exercise Torpedo

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